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GEOTHERMAL INVESTIGATIONS AT MANLEY HOT SPRINGS, ALASKA

A

THESIS

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

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Fairbanks, Alaska

December, 1982

GEOTHERMAL INVESTIGATIONS AT MANLEY HOT SPRINGS, ALASKA

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ABSTRACT

Manley Hot Springs is one of several low-temperature, hot-water dominated hot-spring systems which form a belt extending through the Interior of Alaska. All have formed as the result of circulation of meteoric water along deep-seated fractures near or within granitic intrusives. Near-surface thermal disturbance at Manley Hot Springs is expressed by the presence of 32 springs and one warm (29.1° C) well. The hottest springs are 61° to 47° C and are utilized for space heating and irrigation.

Geophysical and geochemical surveys conducted delineate a 1.2 km by 0.6 km northeast-trending area of shallow, thermally disturbed ground. Based on the above surveys a model is proposed for the geothermal system at Manley Hot Springs which involves circulation of meteoric water to depths of 2.3 km or greater within granitic rock of the Manley Hot Springs Dome stock. Three localities are targeted as likely geothermal well sites.

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INTRODUCTION

Manley Hot Springs lies within the Yukon-Tanana upland physiographic province of the Interior of Alaska, near the junction of the Tanana A-2 and Kantishna River D-2 quandrangles, latitude 65° 00' N, longitude 150° 38' W (Fig. 1). By air, Manley is 145 km west of Fairbanks and 71 km east of the village of Tanana. State Highway 2, known as the Elliott Highway, connects Manley Hot Springs with Eureka, Livengood and Fairbanks along a 260 km gravel-surfaced road. From Manley Hot Springs, a road continues 21 km northeast to Tofty, an old placer mining district. Manley Hot Springs is also connected by a 5 km road to a barge landing on the Tanana River. The village of Manley Hot Springs is situated on the northern margin of the Tanana Valley along Hot Springs Slough, a 13 km long, shallow waterway which drains into the Tanana River. Elevations in the Manley Hot Springs area range from less than 79 m for the Tanana Valley floor, to 808 m for the summit of Hot Springs Dome located to the northwest. The dome is the highest part of a narrow, 43 km-long, northeast-trending ridge known as Bean Ridge, which separates the Tanana Valley from a parallel valley occupied by Patterson and Baker Creeks.

The Manley Hot Springs area lies within the zone of discontinuous permafrost. Normal vegetation consists of thick brush on the upper slopes, and white spruce, black spruce, birch, aspen, poplar and scattered brush on the lower slopes. Trees are up to 0.6 m in diameter. The poorly drained portions of the lowlands consist of

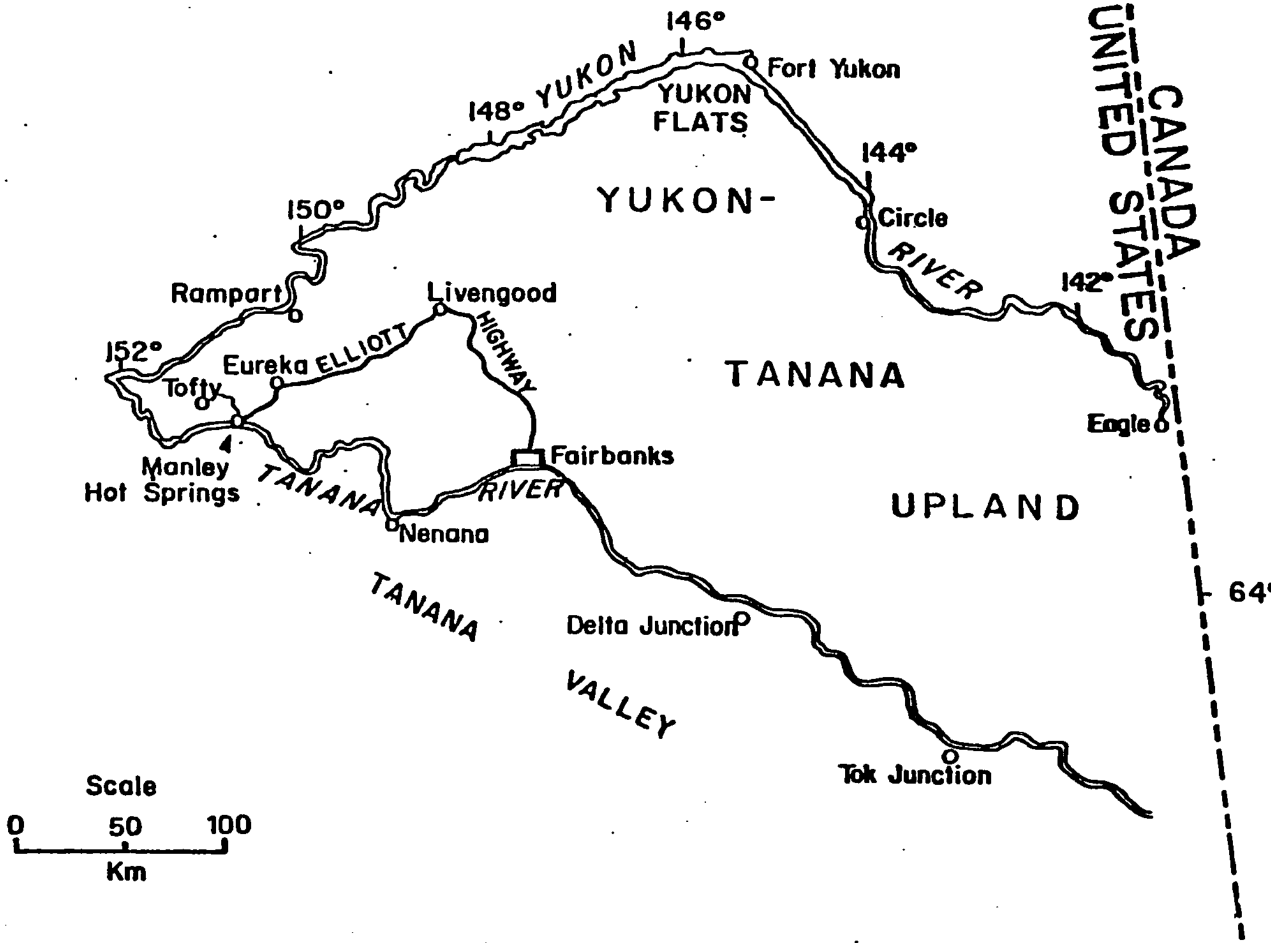


Figure 1: The Yukon-Tanana upland physiographic province showing the location of Manley Hot Springs.

black spruce and muskeg-type vegetation. The climate is typical of the Yukon River valley; long, cold winters and short, warm summers with a possible range of temperatures from 70° F below zero to 98° F above zero. The annual precipitation is 25 to 30 cm, most of which falls as rain through the summer months. The town has a full-time population of about 40 people and an airstrip, post office, store, lodge and elementary school. Power is supplied by three 50 kw diesel generators.

The main hot springs are 0.75 km north of the central part of town, and several occurrences of warm seeps are found within a 0.8 km radius of the main springs. In general, the warm springs and seeps occur near the base of southeast-facing slopes of Bean Ridge near the edge of the Tanana Valley. However, they are localized only along a 1.4 km long portion of these slopes between Ohio Creek and the highway road to Tofty. Charles and Gladys Dart own the hot springs and surrounding 236 acres. They utilize the thermal water for space heating of their home and the operation of a 30 by 45 m green house and a small public bath house. The hot spring water has no noticeable odor or taste and serves as the community's principle water source for drinking, washing, and other uses. The greenhouse is located next to the main springs and is used primarily for raising tomatoes. The tomatoes are sold locally and have also been shipped into Fairbanks. Other hothouse vegetables which are sold locally include cucumbers, eggplants and melons. A few wells have been drilled adjacent to the Dart's land, and one of these has warm (29° C) water. However no wells have been drilled close to the hot springs. Water is piped and used as it flows from the spring mouths. The main pupose of this study was to help delineate targets for drilling of a geothermal well. Thermal water may be mixing to some extent with ground water and/or water from Karshner Creek, so that drilling could result in hotter water with higher rates of flow.

HISTORICAL BACKGROUND

Mertie (1932) reports that the first non-Indian settlement in the Manley Hot Springs area was a trading post established in about 1881, 77 km upstream from Tanana on the Tanana River. Bean's trading post was near the mouth of, or downstream from, the Hot Springs Slough. In 1898 gold was discovered on Eureka Creek and shortly afterwards Eureka became a recognized mining community. Baker Creek about 8 km from the hot springs was the initial site of another early placer district, the Tofty mining district. For several years the town of Rampart was the sole supply point for the camps in the Manley area and winter supplies were hauled over the divide at a rate of 4 cents per pound (Mertie, 1934).

In 1902 the land around the hot springs was homesteaded by J.M. Karshner and his wife and the springs were known as Karshner Hot Springs. In 1906 an enterprising and wealthy prospecter named Frank G. Manley formed a partnership of sorts with Karshner and built a large 60-room hotel and several outer enclosed bathing tanks. They developed the hot springs as a resort and also cleared 60 acres of land and established a dairy, poultry and hog farm, and constructed several greenhouses (Figs. 2-6). Potatoes, cabbages, corn, hay and feed crops were raised on the slopes surrounding the springs. In 1910, 150 tons of potatoes were shipped down river to the Iditarod mining district. The hotel, barns and greenhouses were all heated with water gravity-fed from the springs. To supply the hotel, water was piped a distance of 0.5 km in a 4-inch galvanized

Figure 2: The Manley Hot Springs Hotel with bath house in the background, 1910. University of Alaska Archives, Charles Bunnell Collection.

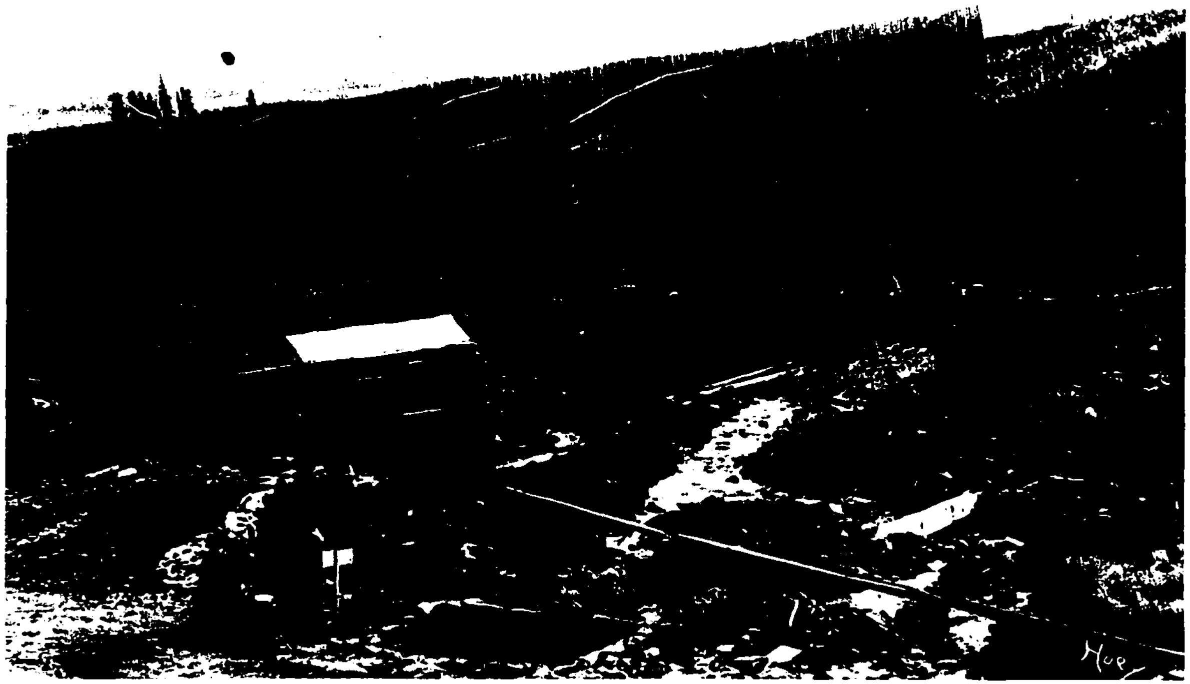


Figure 3: The main springs at Manley Hot Springs, 1910. Note stone cribbing around one hot spring. Karshner Creek flows through the lower half of photo. University of Alaska Archives, Charles Bunnell Collection.

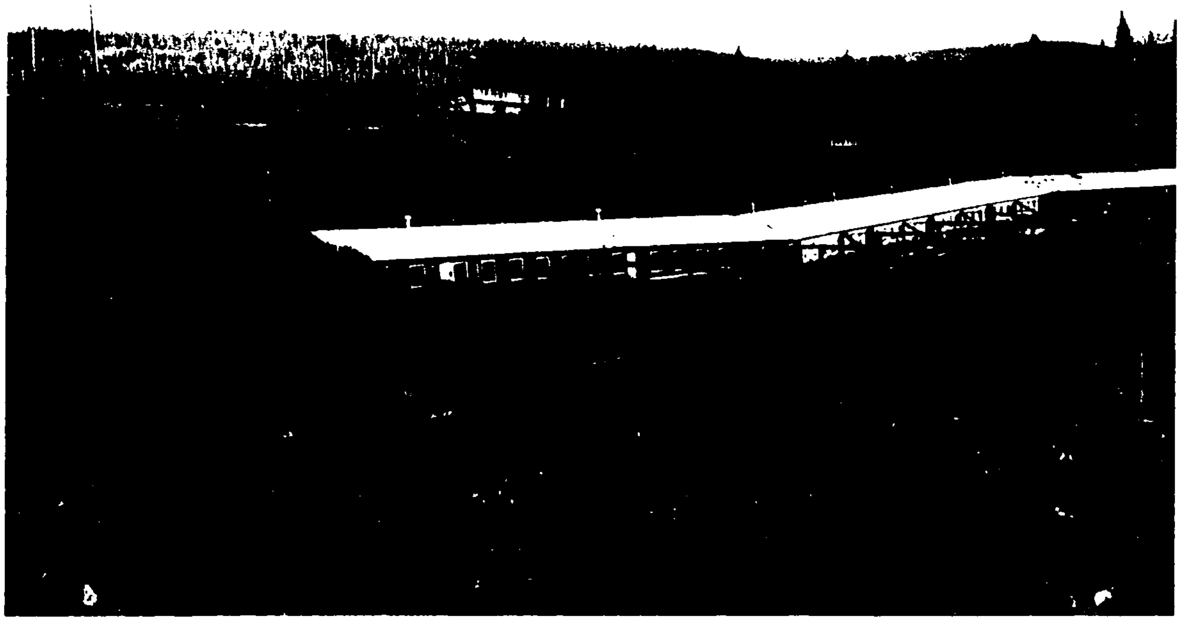


Figure 4: Poultry and hog barns at Manley Hot Springs, 1910. The barns were heated by water carried in buried aqueducts. University of Alaska Archives, Charles Bunnell Collection.

Figure 5: Corn field and potato fields. Note the stone cribbing around one hot spring in the lower left corner. University of Alaska Archives, Archie Lewis Collection.

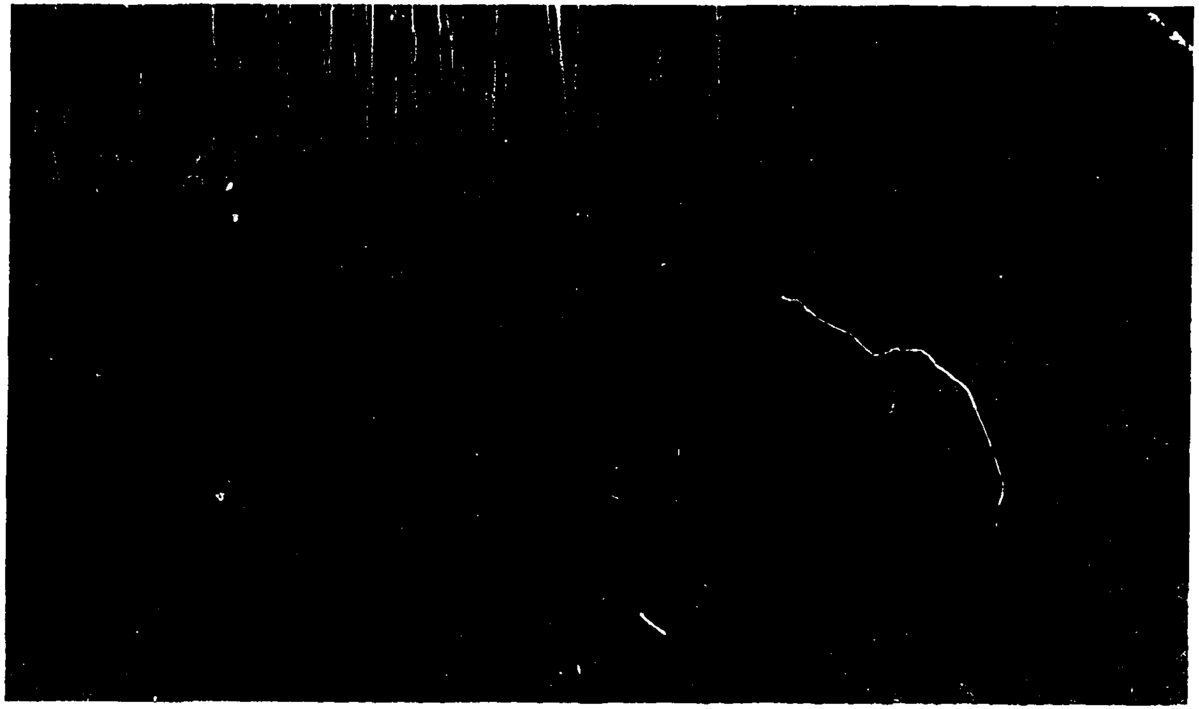


Figure 6: Open air and controlled environment gardening at Manley Hot Springs, around 1910. University of Alaska Archives, Charles Bunnell Collection.

pipe. The town which quickly developed around the site became the supply point for the mining camps in the Eureka and Tofty areas.

By the early 1910's however, the Manley enterprise was falling into a rapid state of disrepair. Placer mining was on the decline and in April, 1913 the hotel burned to the ground never to be rebuilt. The sketch map of Waring (1917) indicates how the hot springs looked in 1915 just past their peak of agricultural production (Fig. 7). Although the Manley-Karshner project was short-lived, its utilization of direct-use geothermal energy on a relatively large scale is unparalleled in the state of Alaska up to the present day. The final patent for the land was issued to Karshner's widow in 1915, and she was obliged to give up the land less than 5 years later. The springs have since had several owners until the final purchase by Charles and Gladys Dart in 1955. The Darts presently own 236 acres of the original Karshner homestead.

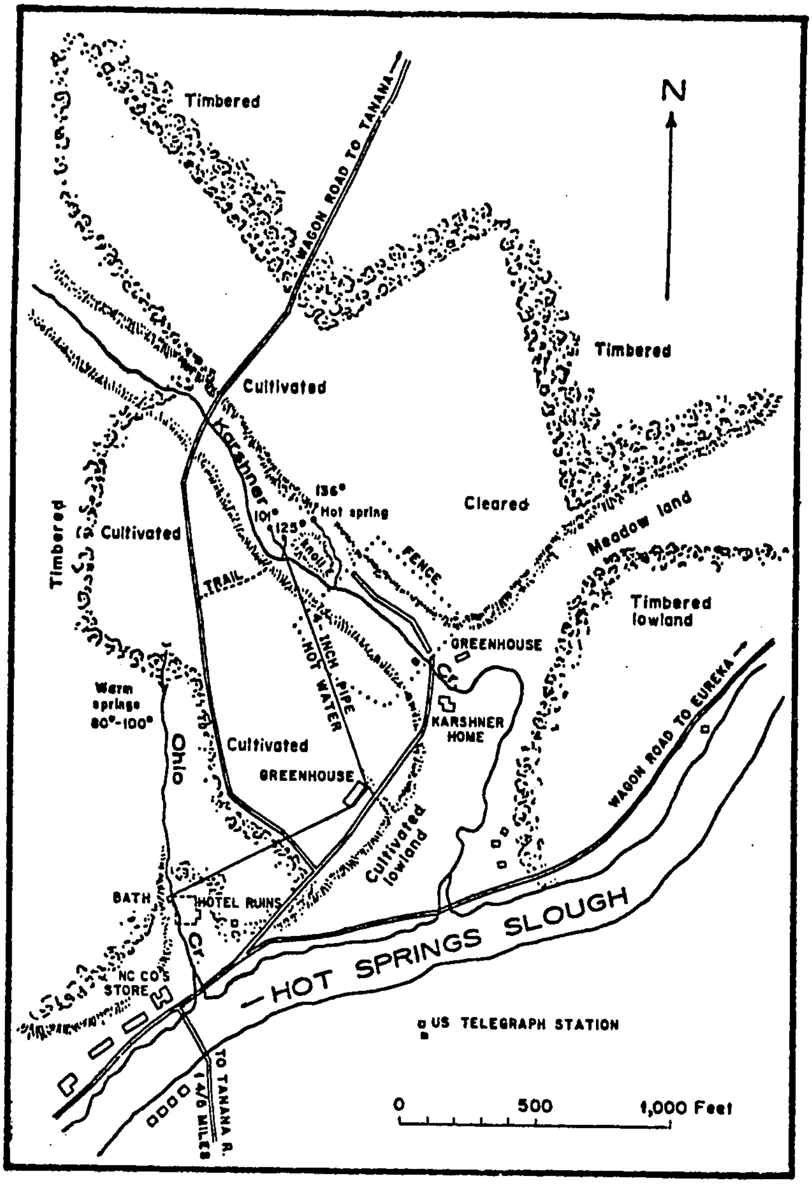


Figure 7: Recreation of a sketch map by G. A. Waring in 1915. From L. Leonard, 1974.

PREVIOUS STUDIES

Geologic Studies

The geology of Manley Hot Springs was first described by Mertie (1932) in a report on the geology of the Yukon-Tanana region. His report was a summarization of investigations by U.S. Geological Survey geologists from 1900 to 1934. During this same period several geologic studies focused on the placer deposits of the Eureka and Tofty districts. The results of these economic studies were incorporated into a report on the mineral deposits of the Rampart and Hot Springs districts (Mertie, 1934).

Hopkins and Taber (1962) conducted a detailed mapping program and geologic study which covered the Tanana A-1 and A-2 quadrangles and that part of the Kantishna River D-2 quadrangle which lies north of the Tanana River. Their findings are presented in an unpublished U.S. Geological Survey preliminary report and accompanying 1:63,360 scale map, which has never been open-filed. Their work represents the most detailed geologic study in the Manley Hot Springs area to date, however it concerns itself primarily with the pre-Quaternary bedded rocks and not with the igneous intrusive bodies and Quaternary deposits.

The U.S. Bureau of Mines has investigated mineral occurrences near the summit of Manley Hot Springs Dome (Maloney, 1971). In 1953 they drilled and logged 8 holes which ranged in depth from 243 ft. to 515 ft. The drill holes were located near the contact between granitic rock and Jurassic-Cretaceous metasediments.

Regional geologic studies by Foster and others (1973) include the Manley Hot Springs area as part of the northwestern part of the Yukon-Tanana upland. In 1975, Chapman and others published a preliminary 1:250,000 geologic map of the Tanana quadrangle. This open-file map incorporated the earlier work done in the Manley Hot Springs area by Hopkins and Taber.

Hot Springs Studies

G. A. Waring, a U.S. Geological Survey geochemist, was the first to conduct a comprehensive geological and geochemical survey of mineral springs throughout the state of Alaska. His findings are published in a 1917 U.S. Geological Survey water supply paper, and include a short but informative report on the springs at Manley Hot Springs, which he refers to as Baker Hot Springs. He noted two main springs, a western and an eastern spring with temperatures of 125° and 136° F (51.6° and 57.8°C), respectively (Fig. 7). These two springs would correspond to springs 1 and 2 as listed in this paper, with 1981 recorded temperatures of 59.4° and 58.9°C. Waring measured respective flow rates of 110 and 35 gallons per minute for the western and eastern springs and analyzed the water from the western spring (spring 1). He also noted a warm marshy area "at the head of a small creek between the main springs and the hotel site." On the sketch map (Fig. 7) he shows this spring area as being at the head of Ohio Creek. This is the same area designated as Site B in this report yet springs from Site B were not observed by this author to form the head of, or drain into Ohio

Creek. Ohio Creek is further to the west and does not appear to show any surficial thermal activity. Waring also noted that the springs had no noticeable odor or taste and that the water tended to corrode iron vessels easily, which he attributed to a high chloride content in the water.

The springs were not further studied until the 1970's when the U.S. Geological Survey conducted a regional program of analysis of hot springs in the interior of Alaska (Miller and others, 1975; Mariner and others, 1978). The silica and Na-K-Ca geothermometers of water from Manley Hot Springs yielded subsurface temperature estimates of 115 and 137° C, respectively. Oxygen isotope studies compared the thermal water with locally derived meteoric water (LDMW). Although the bedrock geology at the springs is not exposed, it was noted that hornfelsed Jurassic/Cretaceous sedimentary rocks crop out 0.8 km up Karshner Creek, and that the granite-metasediment contact is assumed to be nearby. In 1981 several water samples were collected and analyzed by the Alaska Division of Geological and Geophysical Surveys (DGGS). They also measured a flow rate for the main spring area of 1418 l/min. Their results are expected to be published in the near future.

REGIONAL GEOLOGIC SETTING

The Manley Hot Springs area is part of the Yukon-Tanana upland, a hilly and mountainous region of about 77,700 sq. km, bounded by the Yukon River to the north, the Tanana River to the south, and the Alaska-Canada border to the east. The region is mostly unglaciated, yet Quaternary loess mantles large areas. Rock exposure is poor throughout the region because of loess, alluvial, colluvial and vegetative cover. In general the Yukon-Tanana upland is characterized by complexly deformed metamorphic rocks which have been intruded by Mesozoic batholiths and smaller Mesozoic and Tertiary plutons (Foster and others, 1973).

The Yukon-Tanana upland is bounded on the north by the Tintina Fault zone and Yukon Flats. The Tintina Fault is a long-lived major structure. It is an extension of the Rocky Mountain trench in the Canadian Cordillera and may represent the southern continental margin in the early Paleozoic. Ages of movement along the Tintina Fault range from lower Paleozoic to Recent, with predominant movement in the Late Cretaceous. Lateral offset on the order of 400 to 450 km has been documented along the Canadian part of the Tintina Fault, 300 km of this in the late Cretaceous (Templeman-Kluit, 1976).

The southern physiographic boundary of the Yukon-Tanana upland is the Tanana River which separates the upland from the Alaska Range. According to Foster and others (1973), it may also represent a structural boundary based on geomorphic evidence for faulting in the Tanana Valley, although rocks of similar lithology are found on either side of the valley.

Due to major differences in geology, Foster and others (1973) have divided the Yukon-Tanana upland into two parts - a metamorphic complex in the eastern and central part, and a relatively unmetamorphosed northwestern part. The northwestern part, which includes the Manley Hot Springs area, constitutes about one-quarter of the entire Yukon-Tanana upland region (Fig. 8). It is bounded by several major northeast trending faults which may be extensions of the Tintina Fault zone (Foster and others, 1973). According to Chapman and others (1979), the Victoria Creek Fault and parallel faults may be splay faults of the Tintina. Intervening fault blocks may be detached and undergoing variable amounts of right-lateral displacement. A possible splay fault of the Tintina known as the Beaver Creek Fault is located 10 km southeast of Manley Hot Springs and separates highly divergent rock types. South of the fault lies a Paleozoic metamorphic terrain, while to the north lie generally unmetamorphosed Mesozoic sediments. The rocks of the northwestern part of the YukonTanana upland consist of a sequence of complexly folded and faulted sedimentary and metasedimentary rocks interbedded with several volcanic sequences (Hopkins and Taber, 1962). The sedimentary and metasedimentary rocks range in age from Precambr'an or early Paleozoic to middle Tertiary. The pre-Tertiary rocks have been intruded by a serpentinized ultramafic body of probable Cretaceous age and by a complex sequence of Cretaceous-Tertiary

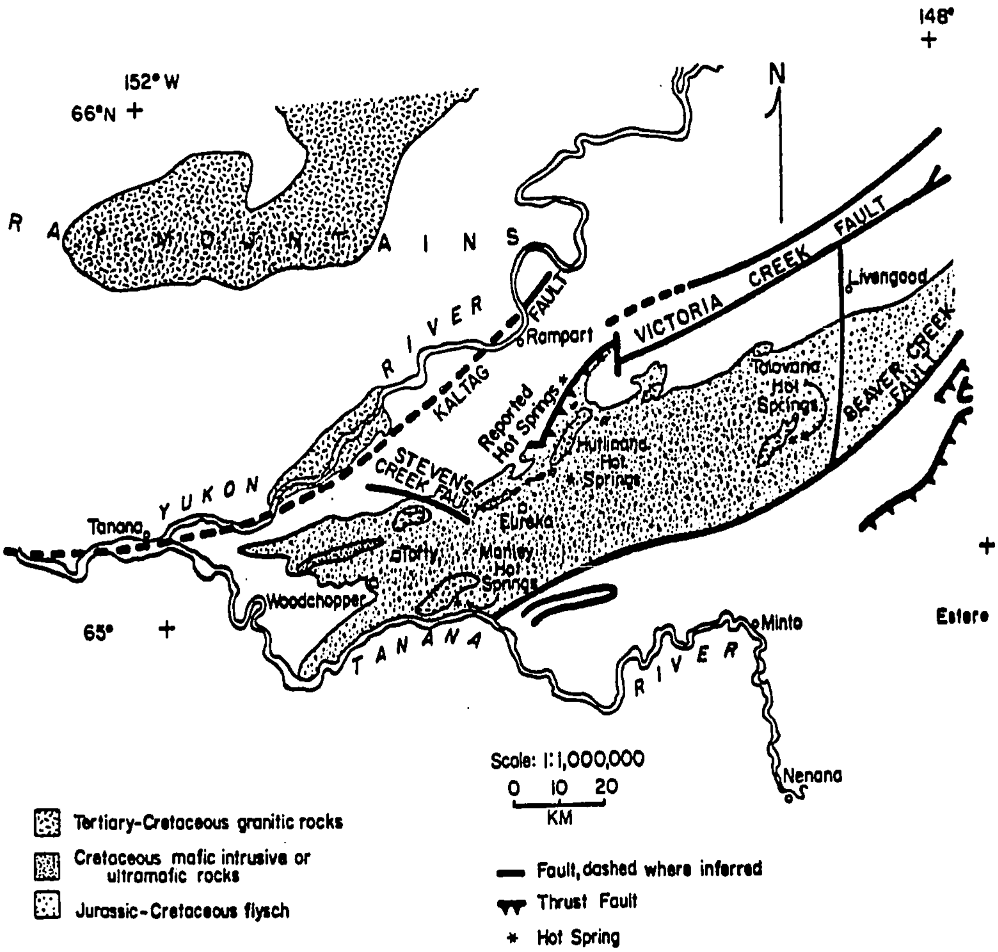


Figure 8: Generalized geologic map of the northwest Yukon-Tanana upland (modified from Beikman and Lathram, 1976).

plutonic rocks ranging in composition from gabbro to biotite granite.

For the purposes of this study, examination of the bedrock geology is limited to those units with which the Manley, Tolovana and Hutlinana Hot Springs are apparently associated. These units are: Jurassic-Cretaceous sedimentary rocks of the informally named "Boulder Ridge Formation" and "Hutlinana Formation" (Hopkins and Taber, 1962), and their metamorphosed equivalents; and granitic stocks of the Manley Hot Springs Dome, Tolovana Hot Springs Dome and Elephant Mountain area.

Jurassic-Cretaceous Sedimentary Rocks

The "Boulder Ridge Formation" and "Hutlinana Formation" form part of a Mesozoic flysch belt which has a maximum width of 40 km and extends northeast 240 km from the Tanana River segment between Manley Hot Springs and Tanana, to Victoria Mountain in the northwest corner of the Circle quadrangle. Except for the southwestern end of the belt, which has been studied in detail by Hopkins and Taber (1962), the formations are simply grouped as KJs/KJc or KJ by other authors (Chapman and others, 1971; Chapman and others, 1975).

The "Boulder Ridge Formation" of Jurassic-Cretaceous age is a sequence of clastic, dominantly marine rocks; chiefly orthoquartzite, slaty siltstone, slate and conglomerate. It rests unconformably on a Paleozoic "eugeosynclinal" assemblage of limestones, cherts, volcanics and clastic sedimentary rocks, and is overlain a with conformable, possibly interfingering contact by the

"Hutlinana Formation". The "Boulder Ridge Formation" was informally named and described by Hopkins and Taber (1962) for its exposures along the north side of Boulder Ridge and north and south sides of Boulder Creek valley. Beds at the base of the formation include the oldest Mesozoic sedimentary rocks exposed in the area. The top of the "Boulder Ridge Formation" is defined as the stratigraphic level where sedimentary rocks begin to consist chiefly of greywacke rather than quartzite, siltstone and slate. Overlying strata are assigned to the "Hutlinana Formation".

The "Boulder Ridge Formation" ranges in thickness from several hundred to several thousand feet. Regional trends in thickness led Hopkins and Taber (1962) to conclude that in their study area the "Boulder Ridge Formation" was deposited in a basin that was generally shallow in the northeastern part but possessed considerable relief. The basin increased in depth to the south and southwest near the present location of Manley Hot Springs and Dugan Hills. Deeper water sections are believed to have been deposited by turbidity and turbidity-related currents. Based on regional trends in average grain size, the direction of sediment transport was to the south and soutwest.

The "Boulder Ridge Formation" is probably of early Cretaceous age, however this age is based on rather scant fossil evidence. The possibility that it is partially or entirely Jurassic cannot be discounted. Rocks of the "Boulder Ridge Formation" have undergone regional and some contact metamorphism. Regional metamorphism has been mild along the margins of the flysch belt, while the central part of the belt, especially the area around the Tofty district, has undergone the most intense metamorphism. Contact metamorphic aureoles of generally high metamorphic grade and varying widths are found throughout the area associated with stocks and dike swarms.

Although the "Hutlinana Formation" is not exposed at or near Manley Hot Springs, it forms the upper part of the Mesozoic flysch belt in the northwestern part of the Yukon-Tanana upland. Hutlinana Hot Springs is located in quartzite beds of the "Hutlinana formation". The "Hutlinana Formation" was informally named by Hopkins and Taber (1962), and defined as a sequence of marine clastic sedimentary rocks that rests conformably upon the "Boulder Ridge Formation". It was named for exposures along the northwest wall of Hutlinana Creek valley. The "Hutlinana Formation" consists chiefly of a monotonous sequence of thick, graded beds of greywacke sandstone, siltstone, and slate. The top of the formation is not exposed in Hopkins and Taber's study area. Thicknesses estimated for the "Hutlinana Formation" range from 1,200 to 18,000 meters. The "Hutlinana Formation" is of probable early Cretaceous age, based on a single Inoceramus fossil. However the lack of strong evidence for a Cretaceous age means there is still a likelihood that the "Hutlinana Formation" is partially or entirely Jurassic. The "Hutlinana Formation" has undergone mild regional metamorphism nearly everywhere in the study area of Hopkins and Taber. In general the intensity of metamorphism follows a pattern similar to that shown by rocks of the "Boulder Ridge Formation". Since it does not crop out close to intrusive contacts the "Hutlinana Formation" displays no contact metamorphic effects.

Tertiary-Cretaceous Granitic Intrusives

Granitic rocks of the northwest part of the Yukon-Tanana upland have mainly been studied in a reconnaissance fashion. They have been mapped by various authors (Hopkins and Taber, 1962; Chapman and others, 1971; Chapman and others, 1975) and briefly described (Chapman and others, 1971), yet little if any work has been done on the petrology, magmatic history or other aspects of these plutons. Potassium-argon ages for five of the intrusives confirm that they are part of a large east-west belt of Cretaceous and Tertiary age granitic plutons which extend through central Alaska.

Plutons and stocks of the northwest Yukon-Tanana upland are elliptical in shape with northeast-trending major axes. They often form prominent peaks and knobs exposed on Manley Hot Springs Dome, Roughtop Mountain, Sawtooth Mountain, Elephant Mountain, Wolverine Mountain and Tolovana Hot Springs Dome. The plutons range in composition from monzonite to quartz monzonite, quartz diorite-granodiorite and granite, and are very light to medium grey in color (Chapman and others, 1971). They are generally well-jointed and irregularly fractured, medium- to coarse-grained, with equigranular, porphyritic, and some fine-grained phases. The surrounding country rock is hornfelsed and highly resistant. Associated small stocks, dikes and sills are composed of granite, with some aplite or pegmatitic texture, rhyolite, monzonite-latite, minette and some mafic differentiates (Chapman and others, 1971).

Age determinations for granitic intrusives in this part of the Yukon Tanana upland are listed in Table 1. Plutons which have been dated are the Manley Hot Springs Dome, Roughtop Mountain-Eureka Dome, Sawtooth Mountain, Tolovana Hot Springs Dome, and a small stock on Troublesome Creek. These five localities yield potassium-argon ages which range from 90 ± 10 m.y. for Roughtop Mountain-Eureka Dome, to 60 m.y. for Manley Hot Springs Dome (Chapman and others, 1971; Hopkins and Taber, 1962).

TABLE 1

Age Determinations for Granitic Plutons
in the Northwestern Yukon-Tanana Upland

Area	Dating Method	Mineral	Age	Rock Composition	Reference
Manley Hot Springs Dome	K-Ar	Biotite	60 m.y.*	Biotite granite	Hopkins and Taber, 1962
Manley Hot Springs dome	Pb-Alpha	Zircon	90 ± 10 m.y.	Biotite granite	Hopkins and Taber, 1962
Roughtop Mtn.-Eureka Dome	K-Ar	Biotite	90 m.y.*	Quartz monzonite	Hopkins and Taber, 1962
Roughtop Mtn.-Eureka Dome	Pb-Alpha	Zircon	90 ± 10 m.y.	Quartz monzonite	Hopkins and Taber, 1962
Tolovana Hot Springs Dome	K-Ar	Biotite	63 ± 2.5 m.y.	Quartz monzonite, monzonite	Chapman and others, 1971
Sawtooth Mtns.	K-Ar	Biotite	88.3 ± 3 m.y.	Quartz monzonite, monzonite	Chapman and others, 1971
Stock on Troublesome Creek	K-Ar	Muscovite	66.4 ± 2 m.y.	Muscovite granite	Chapman and others, 1971

*Standard deviations not reported.

REGIONAL SETTING OF THE HOT SPRINGS

Manley Hot Springs forms part of a regional east-west belt of hot springs all of which appear related to granitic plutons. This belt extends through central Alaska and possibly over to the Chukotka Peninsula of Siberia. As a group, the hot springs of central Alaska belong to the hot water type of geothermal system and not to the vapor-dominated type. Subsurface temperatures based on their chemical geothermometers range from 70° to 160° C. Chemical and isotopic compositions show that the thermal waters are chiefly or entirely meteoric in origin (Miller and others, 1975).

It was noted as early as 1917 by Waring that hot springs of the Alaska interior are characterized by a close spatial association with the contacts of granitic plutons. Miller and others (1975) state that of the 23 hot springs in west-central Alaska whose bedrock geology is known, all are within 4.8 km of a granitic pluton. Age, composition, magmatic history and radiogenic heat production of hot spring-related plutons are quite diverse. This suggests that the hot springs are not a product of thermal transfer by either a cooling magma chamber or anomalous radiogenic heat within the plutons. Because of the age ($> 60 \times 10^9$ yrs.) and low radiogenic mineral content of the plutons it was concluded that thermal activity is due to deep circulation of meteoric water.

The bedrock geology associated with the hot spring sites may have a wide range of lithologies but typically consists of massive, competent, well-fractured and generally non-foliated rock. This applies to both the plutons and the surrounding country rock, if the hot springs are located outside of the pluton. The competent yet fractured nature of the bedrock may allow for good fracture permeability so that meteoric water circulates deeply. Depths of circulation on the order of 2 to 5 km have been proposed by Miller and others (1975). This is the range of depth required assuming a normal geothermal gradient of 30° to 50° C/km for water to attain the reservoir temperatures estimated from their chemistry.

The northwestern Yukon-Tanana upland contains three hot springs: Manley Hot Springs, Hutlinana Hot Springs and Tolovana Hot Springs. A fourth unconfirmed spring has been reported near Little Minook Creek, and it is quite possible that other hot springs may exist in this region, but they have not been reported. The hot spring near Little Minook Creek was reported to Waring (1917) by prospectors, however the spring's exact location is not known. During July, 1981 Mary Moorman and Shirley Liss of the DGGS flew over the Minook Creek area, but were unable to spot any thermal activity (M. Moorman, pers. comm., 1982). If the hot spring does exist, it may be that placer mining activity in the area has obscured it.

As mentioned earlier, Hutlinana and Tolovana Hot Springs exhibit several similarities to Manley Hot Springs. Hutlinana Hot Springs is approximately 39 km northeast of Manley Hot Springs, along the west side of Hutlinana Creek, latitude 65° 13' N, longitude 149° 59' W. The springs issue from the base of a cliff composed of sheared quartzite and hornfelsic greywacke of the "Hutlinana

Formation". Waring (1917) noted that the rock showed "nearly vertical bedding or shearing planes that strike N 25° E" and that these would provide likely avenues for the escape of heated water. Hutlinana Hot Springs is about 5 km east of the Elephant Mountain pluton, which is chiefly porphyritic monzonite and quartz monzonite (Chapman and others, 1971). No faults have been mapped in the Hutlinana Hot Springs area. The temperature of the springs is about 43° C, and it has a discharge rate of about 3 l/s. The springs have a slight smell of H_2S and the silica and Na-K-Ca geothermometers give reservoir temperatures of 92° and 98° C, respectively. The pH of Hutlinana Hot Springs is 7.66, similar to Manley Hot Springs which is 7.7.

Tolovana Hot Springs is about 107 km northeast of Manley Hot Springs, along a creek draining the east side of Tolovana Hot Springs Dome, latitude 65° 16' N, longitude 148° 50' W. The springs are in mudstones which are part of the Jurassic-Cretaceous sedimentary sequence which Chapman and others (1971) refer to as KJs. The mudstones probably correspond in part to either the "Boulder Ridge Formation" or "Hutlinana Formation". The Tolovana Hot Springs Dome stock lies 1.3 km west of the springs and is composed of porphyritic quartz monzonite and monzonite. Between the pluton margin and Tolovana Hot Springs lies a 0.8 km zone of hornfelsed rock (Chapman and others, 1971). There are no faults mapped in or near the Tolovana Hot Springs area. The maximum temperature of Tolovana Hot Springs is about 60° C. The water tastes slightly alkaline, has a pH of 7.7 and there is a faint H_2S odor. The water chemistry of Tolovana Hot Springs differs from the other two springs in that it is saline, with higher concentrations of chloride, sodium, calcium, potassium and perhaps lithium, bromide and boron. Of the 12 springs sampled in west-central Alaska, four springs have high salinities - Tolovana, Pilgrim, Serpentine and Kwiniuk (Miller and others, 1975). All of the saline springs excepting Tolovana, are located on the Seward Peninsula. Saline springs of the Seward Peninsula have pH values which range from 6.75 (Pilgrim Hot Springs) to 7.94 (Serpentine Hot Springs). The high salinity values of these four springs may be due to the increased availability of solutes for leaching within the rock. It may be that the springs which show lower salinity values do so because in the past they were subjected to greater amounts of leaching or for longer periods of time than the saline springs (Miller and others, 1975). Silica and Na-K-Ca geothermometers for Tolovana Hot Springs yield respective subsurface temperatures of 122° and 162° C.

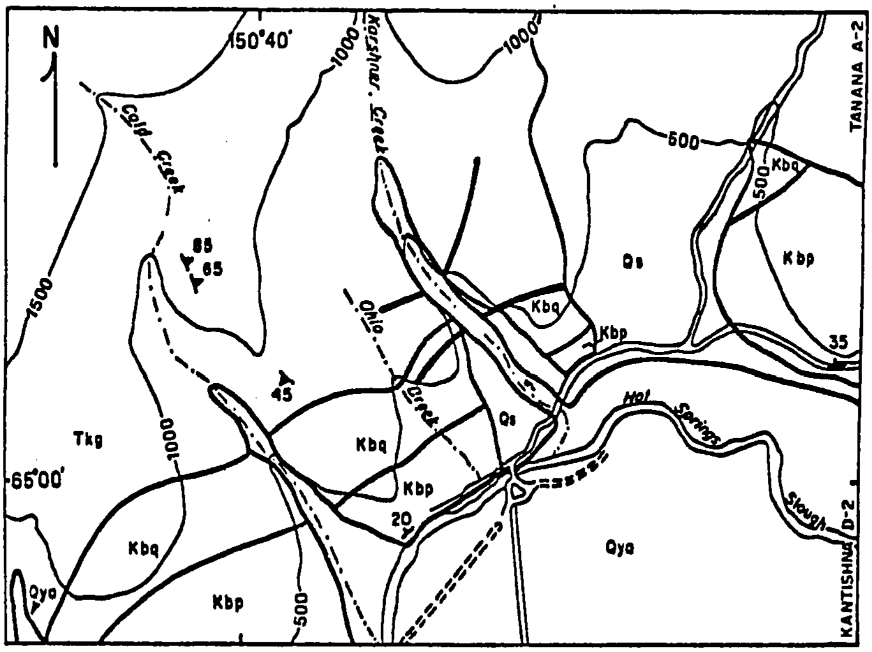
LOCAL GEOLOGY

The local bedrock geology of the Manley Hot Springs area consists of tilted and folded sediments of the Jurassic-Cretaceous "Boulder Ridge Formation", which have been intruded by granitic rocks of the Manley Hot Springs Dome stock (Fig. 9). These rocks are partially mantled by Quaternary loess, colluvium, and alluvium from creeks and the Tanana River floodplain. Surficial deposits and extensive vegetation limit exposures of the bedrock geology to highly scattered and weathered outcrops on slopes and ridges, cliffs bordering Hot Springs Slough, and several gravel pits.

The "Boulder Ridge Formation"

Sediments of the "Boulder Ridge Formation" along the southern flank of Manley Hot Springs Dome strike about N 60° E, parallel to the trend of the Hot Springs Dome stock and Bean Ridge. Beds generally dip to the northwest about 20-40°. The "Boulder Ridge Formation" has been divided into a lower quartzitic and an upper pelitic subdivision (Hopkins and Taber, 1962). The lower subdivision (map unit Kbq, Fig. 9) is mainly fine- to coarse-grained quartzite, with pebble conglomerate and lesser amounts of greywacke. The upper subdivision (Kbp, Fig. 9) is composed of pelitic sedimentary rocks which include slate, slatey siltstone with minor interbedded quartzite.

In the Bean Ridge area the "Boulder Ridge Formation" is approximately 1,070 meters thick. Though exposures are poor, the base probably consists of a 150 to 300 meter section of thin-bedded



LEGEND

	Age	Unit
Scale 1:24,000	Recent	Qya-younger alluvium
	Pleistocene	Qs-loess and reworked loess
	U.Cretaceous or L.Tertiary	Tkg-Hot Springs Dome stock, biotite, granite
Fault Strike and dip Foliation Contact	L.Cretaceous	Kbq-quartzite rocks "Boulder Ridge Formation" Kbp-pelitic rocks "Boulder Ridge Formation"

Figure 9: Geologic map of Manley Hot Springs (from Hopkins and Taber, 1962).

quartzite with rare interbeds of chert pebble conglomerate. The lower section shows graded bedding and bottom markings indicative of deposition by turbidity currents. This sequence grades upward into a laminated sequence several 10's of meters thick of fine-grained quartzite, quartzose siltstone and slate. The upper part of the "Boulder Ridge Formation" in the Bean Ridge area consists principally of slate and siltstone with a few thin beds of quartzite. Near the top there are lenses, concretions, and thin beds of calcareous siltstone.

The thin-bedded quartzite and slate sequence ranges in color from medium to dark grey, darkening in color with increasing proportions of slate. Siltstone is generally medium grey or pale olive. Quartzite and conglomerate beds are very high in chert, with a chert:quartz ratio as high as 1:1. Siltstone grains are composed of quartz, chert, feldspar and calcite, and may also contain large grains of pyrite. Siltstone and slate contain high proportions of graphite and fine-grained white mica.

Regional metamorphic effects on the "Boulder Ridge Formation" are rather mild in the Bean Ridge area. Pelitic rocks show a well-developed slaty cleavage, with recrystallization and reorientation of the original clay minerals and carbonaceous material to fine-grained white mica and graphite (Hopkins and Taber, 1962). The finest grained rocks are fissile, while the silty textured rocks show a cruder and more widely spaced cleavage. Two sets of cleavage planes have been developed in many slate and siltstone beds along the south side of Bean Ridge, so that pelitic rocks commonly disintegrate into rod and pencil-shaped fragments. Beds of quartzose greywacke and conglomerate rich in non-siliceous pebbles also show a poorly developed cleavage resulting from the development of slip planes along which micaceous minerals have been realigned. Quartzite and chert-pebble conglomerate beds have been fairly resistant to deformation and rarely show cleavage. In these beds however, quartz grains may be fractured, strained, and elongated by deformation. In some of the more highly deformed beds there is evidence of chemical redistribution of the original constituents. This includes pyrite porphyroblasts in pelitic beds, overgrowths on clastic tourmaline grains, and abundant quartz veining associated wih orthoquartzite beds.

Contact metamorphism in the Bean Ridge area has resulted in the conversion of original slaty rocks to "knotted" slate. Closer to the granitic margins slates have been converted to hornfels or schist. Sandstone beds have been recrystallized, with increasing intensity, defined by recrystallization of quartz grains, as the intrusive body is approached. On the southern flank of Manley Hot Springs Dome, contact metamorphosed slaty rocks are characterized by the presence of "knotted" slates. The "knots" are less than 1 cm in diameter and are developed on the cleavage planes. In thin section these knots appear as carbonaceous clots or spherules of fine fine-grained white mica (Mertie, 1932; Hopkins and Taber, 1962). On the north side of Manley Hot Springs Dome, the "knots" consist of porphyroblasts of staurolite and andalusite. Pelitic rocks within several 10's of meters of intrusive bodies such as Manley Hot Springs Dome, are more intensely recrystallized to hornfels. Rocks commonly consist of granoblastic mixtures of biotite, quartz, graphite, fine-grained white mica, hematite, and tourmaline. Quartzite beds close to granitic margins show recrystallization of the original rounded quartz grains into coarser, granoblastic quartz aggregates and conversion of original micaceous minerals to biotite. Within several 10's of meters of the margins of Hot Springs Dome, rocks of the "Boulder Ridge Formation" are intimately injected with hydrothermal veinlets composed of quartz, biotite, tourmaline and minor sulfides.

Bedrock exposures are essentially nonexistent at Manley Hot Springs. Quaternary loess and vegetation covers most of the surrounding slopes and hills. Boulders present in Karshner Creek are primarily hornfelsed quartzite and biotite granite. Several hundred meters upstream, near the foot of the western side of Karshner Creek valley, several small weathered outcrops of hornfelsed "Boulder Ridge Formation" can be observed. Approximately 500-800 meters upstream from Manley Hot Springs the pluton-country rock contact is crossed. In general, rocks of the "Boulder Ridge Formation" upstream of Manley Hot Springs are predominantly thin-bedded quartzite with lesser slate and metasiltstone. Rocks cropping out within 40 meters of the Hot Springs Dome stock are medium to dark grey, thin-bedded quartzites with well-defined bedding planes about 1 cm in thickness. The quartz grains appear to be recrystallized and there are 1-2% medium sized grains composed of hematite or limonite. These grains are arranged parallel to bedding and may be sites of earlier pyrite mineralization.

Manley Hot Springs Dome Stock

Granitic rocks of the Manley Hot Springs Dome stock cover an elliptical area approximately 17 km in length and with a maximum width of 5 km. The stock is exposed along the southern flank of Bean Ridge, and its northern contact is nearly parallel to and coincident with the crest of Bean Ridge. The stock has been briefly studied by Hopkins and Taber (1962) who describe it as being chiefly a fine- to coarse-grained, light colored biotite granite. Some small areas of tourmaline granite in or near the border zone were also noted. Leucocratic dikes are common and may be hydrothermally altered. The dikes are composed of rhyolite, and may be aplitic or pegmatitic in nature. The Manley Hot Springs Dome stock has a K-Ar age of 60 m.y. measured on biotite and a Pb-alpha age of 90 ± 10 m.y. measured on zircon (Hopkins and Taber, 1962).

Small metal-bearing lode deposits, located near the summit of Hot Springs Dome have been known to exist since the 1890's. Mineralization is within metasediments along the northern margin of the stock and is associated with shear zones up to 15 meters wide. Drilling was conducted near the summit by the U.S. Bureau of Mines in 1953. Approximately 975 meters of drill hole was completed in 8 holes with depths from 74 to 157 meters. The geologic sections for these 8 holes are published in a Bureau of Mines open file report (Maloney, 1971). It was noted by Maloney that the shear zones near the northern contact of the stock are parallel to the pluton's margin. It was also noted that none of the drill holes intersected primary sulfides with the exception of one small protected pocket. Oxidation was practically complete to 136 meters below the surface, which was the greatest depth reached. This suggests that near the summit there is good permeability - probably associated with jointing in the granite and fracturing in the metasediments, and that water has been extensively circulated to depths of at least 136 meters to oxidize the sulfides.

According to Hopkins and Taber (1962), the Manley Hot Springs Dome stock is asymmetric in cross-section (Fig. 10). Its northern margin may be very steep to vertical. Several steep faults are associated with the northern margin and the stock may in part be faulted against deformed sediments of the "Boulder Ridge Formation". The southern margin is believed to dip gently to the south on the order of 30 to 40 degrees. The pluton may have been emplaced at fairly shallow levels in the crust, based upon the abundance of fine-grained associated dikes.

Unconsolidated Deposits

Bedrock throughout much of the Manley Hot Springs area is mantled by silt, sand and gravel alluvium, colluvium and loess. The loess forms deposits of 5 to 30 meters or more in thickness along low hills and slopes. The loess is massive, homogeneous eolian silt, buff to tannish grey when dry and brown when wet. The period of loess deposition was approximately 25,000 to 10,000

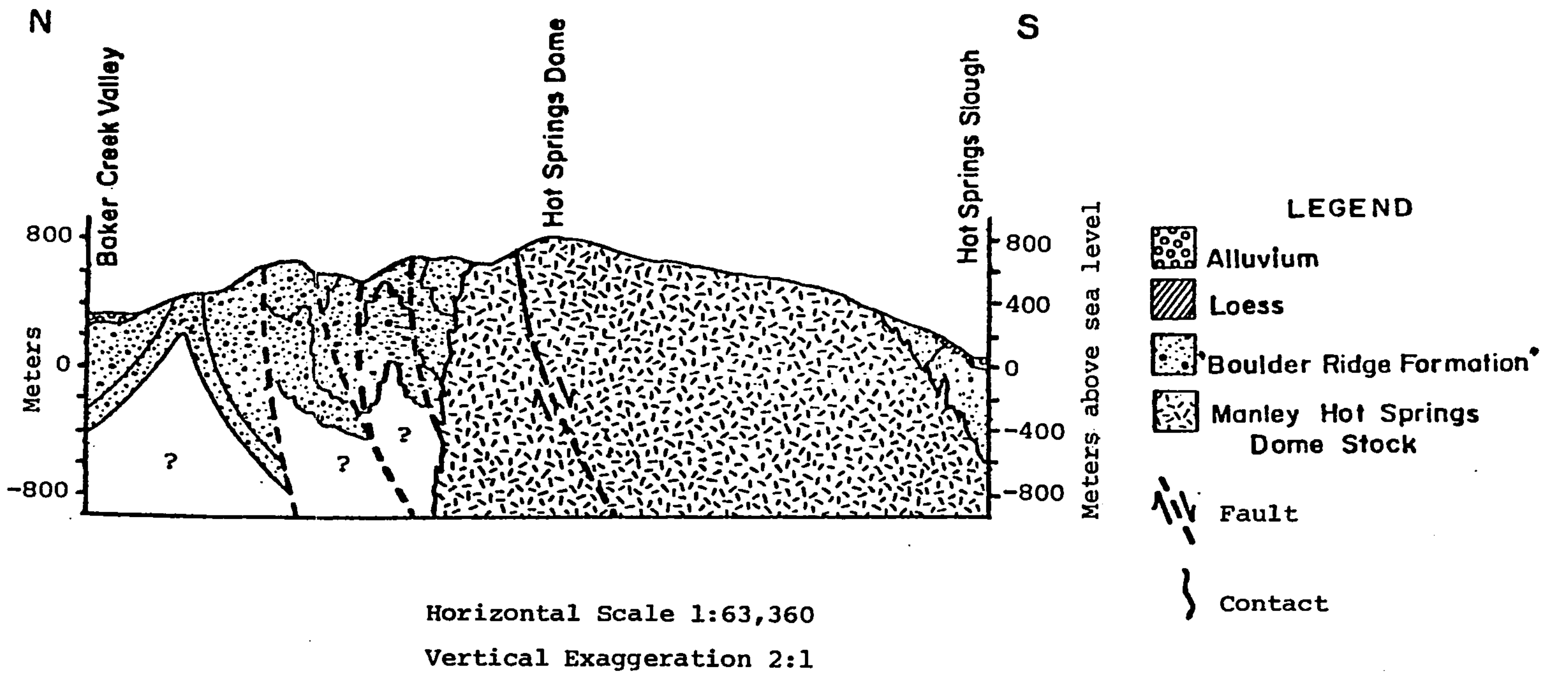


Figure 10: Idealized cross-section of Manley Hot Springs Dome (modified from Hopkins and Taber, 1962).

years ago (D. Hopkins, pers. comm., 1981). Loess of an undetermined thickness is found in the lower part of Karshner valley at the hot springs. Karshner Creek has cut through at least 10 meters of loess, yet it is not certain whether the creek is close to bedrock, or is resting on several meters of loess. The loess-metasediment contact is not exposed in Karshner valley.

The floor of Karshner valley is covered by vegetation and alluvium. The alluvium is composed dominantly of sand and gravel, but ranges in size from clay to large subrounded boulders. The boulders may have been transported from a considerable distance upstream during occasional periods of high flood. At least two knolls are noted along the sides of Karshner valley. They are composed of alluvium and may represent stream terraces. Hot springs and seeps issue near both knolls.

Structure

Along the northern flank of the Manley Hot Springs Dome, the "Boulder Ridge Formation" appears to be complexly folded and faulted. Faults along the crest and the northern side of Bean Ridge strike east-west or northeast, subparallel to the trend of the ridge. Faults on the north side are characterized by predominantly vertical displacement (Hopkins and Taber, 1962).

In general, Jurassic-Cretaceous sediments on the southern flank of Manley Hot Springs Dome dip moderately to gently to the north. Few faults have been mapped on the southern flank of dome. It may simply be that faults are not detected due to the lack of outcrop. However, the presence of the hot springs in this area suggests that a deep-seated fault system may supply the plumbing for the thermal water at Manley Hot Springs. An alternative possibility is that well-developed fracture permeability in the bedrock may be responsible for the springs. Using aerial photographs, Hopkins and Taber (1962) mapped several linear trends within granitic rock upstream of the hot springs in the Karshner Creek drainage. These linears strike approximately N 50° E. An arcuate fault shown upstream from the hot springs in Figure 9 was also mapped by Hopkins and Taber on the basis of aerial photographs. The Beaver Creek Fault, located 10 km to the southeast, may be a splay of the Tintina Fault. Therefore the possibility of fault activity in the Manley Hot Springs area cannot be discounted. The Beaver Creek Fault appears to die-out to the southwest underneath the Tanana Valley floodplain.

METHODS OF INVESTIGATION

The major portion of the field work for this study was carried out during a two month period between May 13 and July 17, 1981, with one preliminary day in mid-March, 1981, spent at Manley Hot Springs taking aerial photographs and collecting several soil samples. A report for the U.S. DOE was completed in Spring, 1982 (East, 1982).

The thermistor, resistivity instruments and helium equipment were loaned from the Geophysical Institute, University of Alaska, Fairbanks. The Alaska DGGS provided water sampling equipment. Helium and water analyses were done respectively through Western Systems Inc., Evergreen, Colorado and the Alaska DGGS. Mercury soil-sample analysis was done by the author during the fall of 1981, using a Jerome Instruments mercury detector provided by the Geophysical Institute.

GRID SYSTEM

A grid system was surveyed early in the field season with north-south and east-west coordinates and a spacing interval of 15 m (Figs. 11-12). The north-south and east-west base lines intersect 15 m northwest of the greenhouse. The grid was surveyed with a tape and Brunton compass.

The network covers the thermally disturbed ground at the main springs, which was apparent in aerial photos taken earlier that spring. It was also intended that the grid extend from the main springs far enough to reach 'background' or non-thermal ground, and that the grid should also intersect seep sites to the southwest and to the southeast. The final grid has an east-west baseline of 570 m, a north-south baseline of 330 m, and contains 285 sample points. Mercury soil-sampling, temperature, helium and resistivity surveys were carried out over this grid. The grid also provided a framework for detailed mapping of the springs, seeps, creeks and other geographic features.

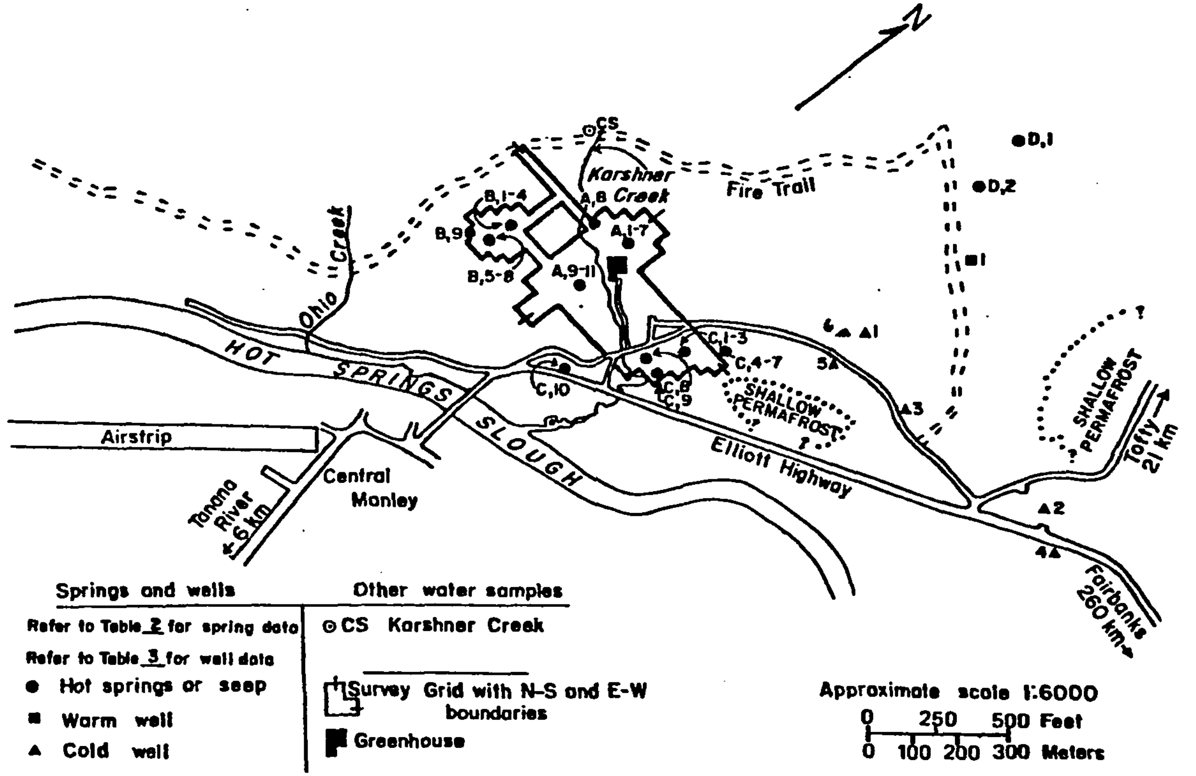


Figure 11: Manley Hot Springs showing location of grid and surrounding springs and wells.

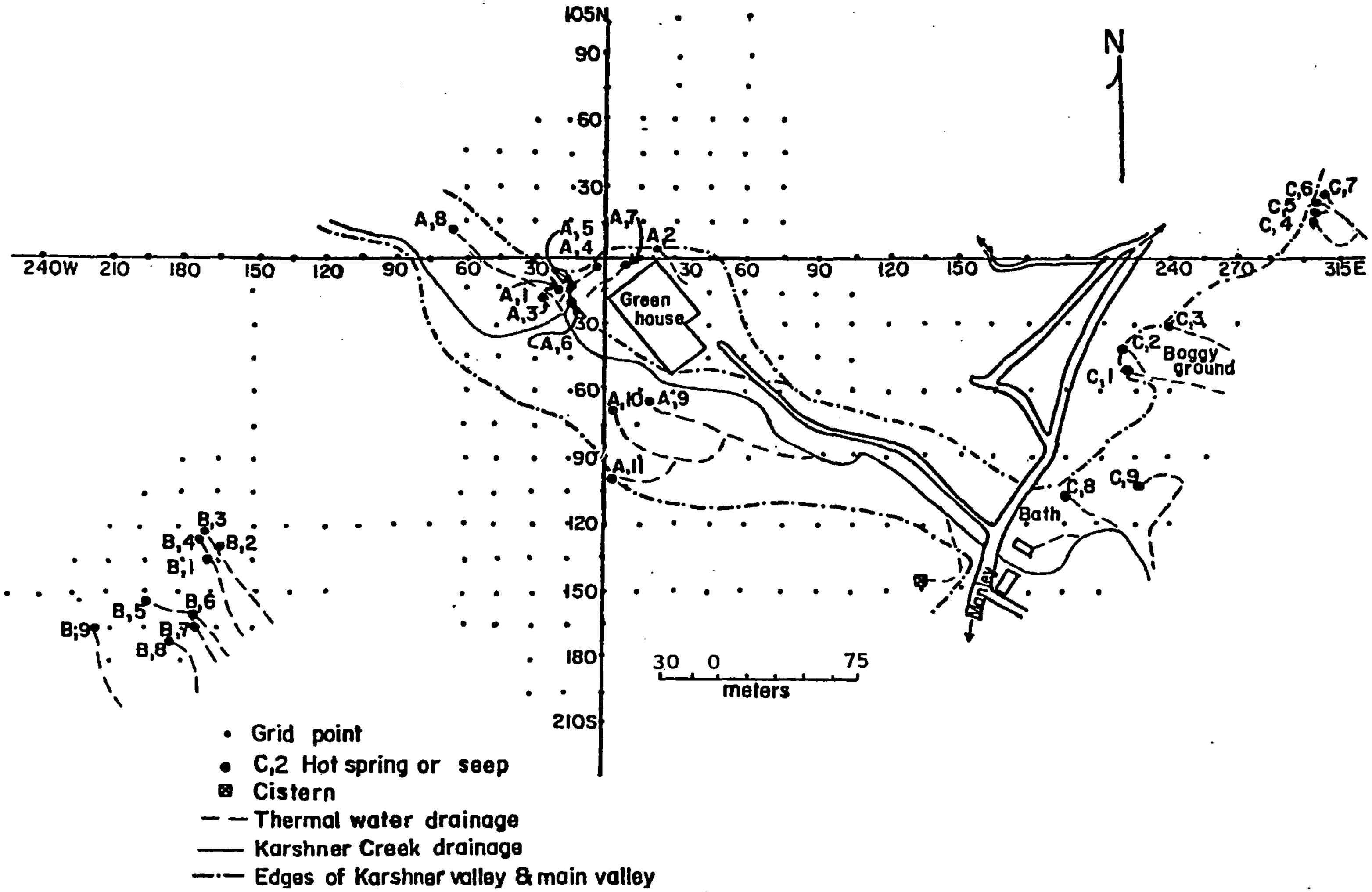


Figure 12: Location of grid at Manley Hot Springs.

HYDROLOGY

Knowledge of the hydrology of the Manley Hot Springs area is based on information from springs, seeps, wells and creeks located near the base of the south side of Bean Ridge. This study was restricted to a belt which is 1.5 km long and located east of Ohio Creek and west of the road to Tofty. Several sites within this belt show evidence of hydrothermal activity; outside of this belt no surface expressions of hydrothermal activity were either noted by the author or known to exist by local residents. There are no cold springs present in the study area.

Hot Springs and Seeps

A spring or seep as defined by the author is a point where water can be observed to issue from the ground and which shows no evidence of drainage from a point at the surface further upslope. By this definition 32 hot springs and seeps were mapped in the Manley Hot Springs area. Flow rates have been roughly estimated for all the springs and seeps. Only the main springs have accurately measured flow rates. A seep is considered to have a much lower flow rate than a spring.

In general, hot springs and seeps can be divided into four sites, known as Sites A, B, C and D. In this report, individual springs are designated by a site letter and a number (i.e.: C,2 is Spring 2 of Site C). Table 2 lists the springs and their maximum temperatures. Temperatures were measured with a thermistor probe. None of the springs or seeps had a noticeable odor or taste. Water samples for

TABLE 2

Hot Springs and Seep Temperatures

Spring (Site, Number)	Temp. (°C)	Type of Analysis
A,1	59.5	Water, Isotope
A,2	58.7	Water, Isotope
A,3	60.7	
A,4	46.8	
A,5	45.7	Isotope
A,6	51.3	
A,7	30.7	
A,8	16.3	
A,9	20.2	
A,10	26.0	
A,11	19.0	
B,1	32.0	Water, Isotope
B,2	28.3	
B,3	22.9	
B,4	26.2	
B,5	20.0	
B,6	28.6	
B,7	28.0	
B,8	17.7	
B,9	24.2	
C,1	23.0	
C,2	29.0	
C,3	31.8	
C,4	33.2	
C,5	33.1	Water, Isotope
C,6	33.0	
C,7	32.8	
C,8	42.8	
C,9	38.6	
C,10	21.0	
D,1	25.4	Water, Isotope
D,2	21.7	

chemical and oxygen isotope analysis were collected for A,1; A,2; B,1; C,5; and D,1. All of the sites are located on land which was part of the original Karshner homestead and is presently owned by the Darts.

Site A contains 11 measured hot springs and seeps which range in temperature from 60.7° C to 16.3° C. They lie at a mean elevation of 94.5 m, along the walls and floor of Karshner Creek valley. Springs A,1-3 constitute the main springs, possessing higher temperatures and rates of flow than any other springs at Manley. These three springs are utilized presently for spaceheating, irrigation and other purposes. The water chemistry of springs A,1-3 has been analyzed by several authors (Waring, 1917; Miller and others, 1975; Mariner and others, 1978). The three main springs and several smaller ones (A,1-7) issue from a knoll or terrace along the north wall of Karshner Valley. They issue from points with an elevation range of about 7 meters, from the lowest to the highest spring. The knoll appears to be composed of unconsolidated sandy and silty gravel alluvium, and may represent an older alluvial terrace of Karshner Creek. In March, 1981, Moorman and Liss of the DGGS measured a total flow rate of approximately 1418 l/min for springs A,1-8.

Other seeps of Site A, springs A,9-11, are located on the south side of Karshner Creek downslope from the main spring area. They issue from the base of a low knoll and from the valley floor. Springs A,8-11 are characterized by low rates of flow, probably less then 5-10 l/min. All the springs and seeps from site A drain into Karshner

Creek, and increase the temperature of the creek considerably. There is a proliferation of blue-green algae both in spring drainages and in Karshner Creek after thermal mixing has taken place. Coatings of calcareous sinter up to 0.5 cm thick are present on rocks around the springs of Site A.

Site B is located in a shallow depression on the side of a hill, approximately 200 meters west of Site A. The site is at a mean elevation of about 113 m. Nine seeps were measured at Site B, with a range of temperatures from 32.0° C to 17.7° C. The seeps form a northeast-trending belt along the lower half of an open and marshy meadow. The individual seeps at Site B are characterized by very low rates of flow, less than 5 l/min. Site B may be an example of a eutrophic spring, consisting of a single point of issuance for the thermal water (Mary Moorman, pers. comm., 1981). The spring however, becomes cooled and diffused as it filters through an upper organic-rich soil horizon. This leads to the surface expression of several cooler seeps, rather than a single hot spring. There is a conspicuous absence of trees in the area surrounding Site B which might be explained by poor drainage. The seeps at Site B flow downslope and coalesce into a single drainage which enters the Hot Springs Slough just west of the bridge. There are blue-green algae and small amounts of calcareous sinter present near the mouths of seeps A,5-8.

Site C consists of several small groups of seeps and springs which are southeast of the main springs and distributed along the edge of the main (Tanana) valley. Site C is the lowest of the four sites, with a mean elevation of of 85 m. Nine springs and seeps were measured, with temperatures ranging from 42.8° C to 23.0° C. Seeps C,1-7 form near the base of a steep hill which is composed of loess. The seeps form small, marshy areas. Seep C,10 is located at the base of a steep hill next to the road which runs into Manley Hot Springs. Springs C,8 and C,9 are located in a flat open area below the bath house at the intersection of Karshner Creek valley and the main valley. In general, seeps C,1-7 and C,10 have low rates of flow, probably less than 5 l/min. Springs C,8-9 have moderate rates of flow of approximately 15-25 l/min. The springs and seeps of site C flow southwest along the edge of the main valley and eventually drain into the lower portion of Karshner Creek. Minor amounts of blue-green algae and calcareous sinter are associated with them.

Site D is about 0.8 km north of the main springs. The site is at a mean elevation of approximately 152 m, making it the highest of the four sites. Two seeps were measured, with temperatures of 25.4° C and 21.7° C. The seeps are located near the heads of two adjacent valleys and form the first signs of running water along the creek floors. The valleys are narrow and steep-walled. The surrounding hills consist of loess which is covered by trees and lush vegetation. Although there is a thick vegetative cover the loess appears to be undergoing extensive erosion expressed by steep, irregular topography suggestive of badlands topography. Seeps D,1-2 have low rates of flow, less than 5 l/min. The thermal water flows downstream, eventually mixing with cooler surface runoff water, which drains into the valley west of the road to Tofty. Seeps at Site D show minor amounts of calcareous sinter.

Wells

There are seven water wells present within the eastern part of the study area. One or two more wells may be present which the author was unable to locate. The well localities are plotted on Fig. 11 and a summary of well data is listed in Table 3. The table and text notation for wells is as follows: cold well, CW; warm well, HW. These letter symbols are followed by a number indicating the specific well. Wells were located and mapped on BLM 1:6,000 aerial photos. If the well was not capped, a container was lowered down inside the casing. The water level below the surface was recorded, and the temperature of the water brought up in the container was measured using a thermistor probe.

All of the wells are under private ownership, except for the highway maintenance yard well. Of the seven wells in the study area all but one are cold water wells. CW-5 is capped so little information was obtained on it, yet it is believed to be a cold well. Of the cold water wells three are currently in use. Wells CW-3 and CW-6 are for residential use and well CW-4 is used by the Highway Department.

The warm water well HW-1 is about 0.6 km northeast of the main hot springs. The temperature measured was 29.1° C, however this is the temperature of standing water about 0.5 m below the water surface. The well was drilled several years ago and is not currently in use. A water sample was taken of HW-1 for analysis of major chemical constituents and oxygen isotopes.

TABLE 3

Water Wells and Miscellaneous Samples from Manley Hot Springs

Water Sample	Temp. (°C)	Comments	Type of Analysis
HW-1	29.1	Warm well Frank Shelton, owner Water level 16 m below surface Approximately 30 m deep	Water, Isotope
CS-1	1.5	Karshner Creek Upstream of hot springs	Water, Isotope
CW-1	12.0	Greg Neubauer, owner Water level 11 m below surface	
CW-2	9.0	Approx. temp. Robert Miller, owner Water level 11 m below surface	
CW-3	15.0	Approx. temp. Robert Miller, owner Well presently used	
CW-4	15.0	Approx. temp. State Hwy. Maintenance well Approx. 30 m deep	
CW-5	U	Bill Waugeman, owner Well is capped	
CW-6	20.6	Kurt Madison, owner 29 m deep, water at 21 m, flow 11 l/min	

U = Undetermined

Karshner Creek

Karshner Creek is one of several creeks which drains the southern side of Bean Ridge and is the only creek present in the study area. The creek drains an area of approximately 3.8 km^2 and is fast-moving in the summer months. During the summer the temperature of Karshner Creek is approximately 2-5° C measured upstream from the hot springs. Much of the creek water is probably the result of snow and ice melt. Water was collected and analyzed for major chemical constituents and oxygen isotopes, and is listed in Table 3 as CS-1.

WATER CHEMISTRY

Five hot spring samples were analyzed for major chemical constituents and include two of the main hot springs of Site A and one seep from each of three other sites (A,1; A,2; B,1; C,5; D,1). In addition, waters were analyzed from warm well HW-1 and from Karshner Creek (CS-1) upstream of the hot spring area. All of the samples were analyzed by Mary Moorman of the Alaska DGGS. Samples for isotopic analysis were also collected at each of the above localities.

A list of the major chemical constituents is given in Table 4. In addition, a cold water well sample (CW-4) was analyzed by Northern Testing Laboratories, Fairbanks, Alaska, for the community of Manley Hot Springs. Some of the data from this analysis is also listed, although it is by no means complete. A temperature-calibrated pH could not be obtained from HW-1 as the well is not presently being pumped. In addition, the silica and calcium values from this well are anomalously low, even when compared with the water from Karshner Creek. Since the water is standing in the well, it could be that the silica and calcium have reequilibrated, however this still does not completely explain the very low SiO_2 and Ca values. It would be worthwhile to pump this well and resample after a good flow is obtained.

In general, the water chemistry at Manley Hot Springs is similar in most respects with hot springs of west-central Alaska, with similar concentrations of the major elements and similar levels

TABLE 4

Chemical Analysis of Water Samples. Concentrations are in Ppm, Specific Conductance is in Units of Millimhos/Meter.

	A,1	A,2	B,1	C,5	D,1	HW-1	CS-1	CW-4
Temp (°C)	59.5	58.7	32.0	33.1	25.4	29.1	1.5	15
SiO_2	65	65	59	47	50	3	20	u
Ca	8.2	7.6	8.4	11.2	12.2	2.2	3.0	u
Mg	0.11	0.06	0.74	1.11	1.34	0.16	0.50	u
Na	145	148	123	111	101	109	2.9	12.6
K	4.60	4.70	3.57	2.98	2.95	3.11	0.24	u
Li	0.29	0.30	0.21	0.17	0.16	0.19	0.0	u
F	8.3	8.6	7.2	6.5	4.4	5.9	0.12	0.99
Fe	0.0	0.04	0.0	0.0	0.0	0.0	0.12	0.99
Sr	0.10	0.10	0.03	0.05	0.10	0.02	0.01	u
pH	8.20	8.35	7.14	7.65	6.64	u	6.41	u
Specific Conductance	850	810	650	615	520	540	32	u
Alkalinity (mg/l HCO_3)	90	93	81	99	68	40	10	u
Cl	153.0	191.5	182.0	134.0	147.0	191.5	<37.0	u

u = undetermined

of bicarbonate present. The water from Manley Hot Springs has a moderately high chloride level and is slightly more saline than many of the Interior springs. This may be due to a longer residence time in the reservoir. One noteworthy element is flouride, which has anomalously high concentrations at Manley Hot Springs, ranging from 4-8 ppm compared to other springs of the Interior with values of generally less than 4 ppm.

Reservoir temperatures were calculated for the water, using the equations listed in Table 5. The results are listed in Table 6. The reservoir temperatures based on silica and cation geothermometers for the main spring samples (A, 1 and A,2) have been earlier calculated by Mariner and others (1978) and correspond closely to those calculated by this author. Several assumptions must be made in appying silica and cation geothermometry to estimations of reservoir temperature. These include: (1) a temperature-dependent reaction at depth, (2) a sufficient abundance of the constituents involved in a temperature-dependent reaction, (3) water-rock equilibrium at depth, (4) negligible re-equilibration as the water flows to the surface, and (5) no dilution or mixing of hot and cold water (Fournier and others, 1974).

Since springs A,1 and A,2 have higher temperatures and flow rates than other springs at Manley, it follows that their geothermometers should yield temperatures most closely approximating that of the deep-level reservoir. Their water chemisty would have the least likelihood of re-equilibration at some shallower level, and

TABLE 5

Equations for calculation of selected geothermometers used in Table 6. C is the concentration of silica. All concentrations are in mg/kg.

Geothermometer	Equation	Restrictions
A. Quartz - adiabatic	$t°C = \frac{1309}{5.19 - \log C} - 273.15$	$t = 0°C - 250°C$
B. Quartz - conductive	$t°C = \frac{1522}{5.75 - \log C} - 273.15$	$t = 0°C - 250°C$
C. Chalcedony	$t°C = \frac{1032}{4.69 - \log C} - 273.15$	$t = 0°C - 250°C$
D. α - Cristobalite	$t°C = \frac{1000}{4.78 - \log C} - 273.15$	$t = 0°C - 250°C$
E. β - Cristobalite	$t°C = \frac{781}{4.51 - \log C} - 273.15$	$t = 0°C - 250°C$
F. Opal	$t°C = \frac{731}{4.52 - \log C} - 273.15$	$t = 0°C - 250°C$
G. Na/K (Fournier)	$t°C = \frac{1217}{4.52\ (Na/K) + 1.483} - 273.15$	$t > 150°C$
H. Na-K-Ca ($\beta = 4/3$)	$t°C = \frac{1647}{\log\ (Na/K) + \beta[\log(\sqrt{Ca}/Na) + 2.06] + 2.47} - 273.15$	$t < 100°C$
I. Na-K-Ca ($\beta = 1/3$)	$t°C = \frac{1647}{\log\ (Na/K) + \beta[\log(\sqrt{Ca}/Na) + 2.06] + 2.47} - 273.15$	$t > 100°C$

TABLE 6

Reservoir Temperatures in ^{o}C Calculated from Geothermometers.

	QUARTZ						CATION		
Water Sample	Adiabatic	Qtz. Conductive	Chalcedony	α Cristobalite	β Cristobalite	Opal	Na/K (Fournier)	Na-K-Ca (β = 4/3)	Na-K-Ca (β =1/3
A,1	114	113	86	64	16	-3	135	98	130
A,2	114	113	86	64	16	-3	135	100	131
B,1	110	109	80	59	12	-7	130	86	124
C,5	99	100	69	49	2	-16	125	73	117
D,1	101	102	71	50	4	-15	130	70	119
HW-1	5	15	-28	-41	-79	-92	129	112	131
CS-1	65	71	33	16	-28	-45	201	1	122

also would be less likely to undergo dilution by cooler ground waters. The best temperature estimates for the deep-level reservoir are based on a quartz-conductive geothermometer value of 113°C and a cation geothermometer value of 130-131°C. The quartz-conductive silica geothermometer assumes that the thermal water is equilibrating with quartz rather than some other silica phase. This would be the case if the reservoir is within granitic rocks of the Manley Hot Springs Dome stock. The Na-K-Ca cation geothermometer takes into account the influence of Ca on the cation geothermometer in moderately low-temperature (< 180°C) thermal waters (Fournier and Truesdell, 1973). The empirically derived equation is shown on Table 5, H and I. Equation H with $\beta = 4/3$ is used for equilibration temperatures of less than 100°C, while equation I with $\beta = 1/3$ is used for temperatures greater than 100°C. Since the equilibration temperature of water at Manley Hot Springs is greater than 100°C when $\beta = 4/3$ is used, the use of $\beta = 1/3$ is the most likely temperature estimate for the Na-K-Ca cation geothermometer. The silica and cation geothermometers give upper and lower temperature limits for the deep-level reservoir of 113°C and 130°C respectively. This corresponds to depths of 2.3 to 2.6 km if a geothermal gradient of 50°C/km is used, and 3.8 to 4.3 km if a gradient of 30°C/km is assumed.

Samples were collected for isotopic analysis including three samples from Site A (main springs) and one each from Sites B, C and D, as well as a sample from Karshner Creek before thermal mixing and from warm well HW-1. H^2 and O^{18} analyses were done at the

Scottish Universities Research and Reactor Centre, Scotland. Analyses are reported with ± 1.0 for H^2 and ± 0.1 for O^{18} at one standard deviation. H^2 and O^{18} variations are given as δ - values in permil (parts per thousand or °/°°), defined as:

$$\delta\ {}^\circ/_{\circ\circ} = \left[\frac{R_{sample}}{R_{smow}} - 1 \times 100\right]$$

where R is the isotope ratio H^2/H or O^4/O^{16}. These data are listed in Table 7 and plotted on a graph of δH^2 vs δO^{18} in Figure 13. Data in Figure 13 are shown relative to the meteoric water line defined by the equation $\delta H^2({}^\circ/_{\circ\circ}) = 8\delta O^{18} + 10$. In general it can be noted that with the exception of sample C,5 all samples fall close to or essentially on the meteoric water line regardless of their thermal or non-thermal affinities. There are slight variations in δH^2 and δO^{18} compositions among the population but these are attributed to analytical and sampling error. For example, springs A,1, A,2 and A,5 are all within several meters of each other and are probably derived from the same shallow-level reservoir. However they have slightly differing δD and δO^{18} values.

Many geothermal areas show a distinct shift toward enrichment of O^{18} in their thermal waters relative to their local groundwaters (Panichi and Gonfiantini, 1978). This O^{18} enrichment has been attributed to water-rock reactions within the geothermal reservoir. The O^{18} shift does not appear to be present at Manley Hot Springs and may be due to the thermal water's having too short a residence time, thus not allowing for O^{18} exchange to take place. It may also be due to the reservoir's lower temperatures. Although sample

TABLE 7

δO^{18} and δH^2 (deuterium) values given in permil (°/°°)

Sample	δO^{18}	δD
A,1	-18.7	-139.5
A,2	-18.6	-135.5
A,5*	-19.4	-141.2
B,1	-19.0	-139.9
C,5	-17.4	-140.7
D,1	-18.8	-139.8
HW-1	-18.8	-138.3
CS-1	-18.5	-138.6

*Sample collected by M. Moorman, Alaska DGGS, Spring 1982.

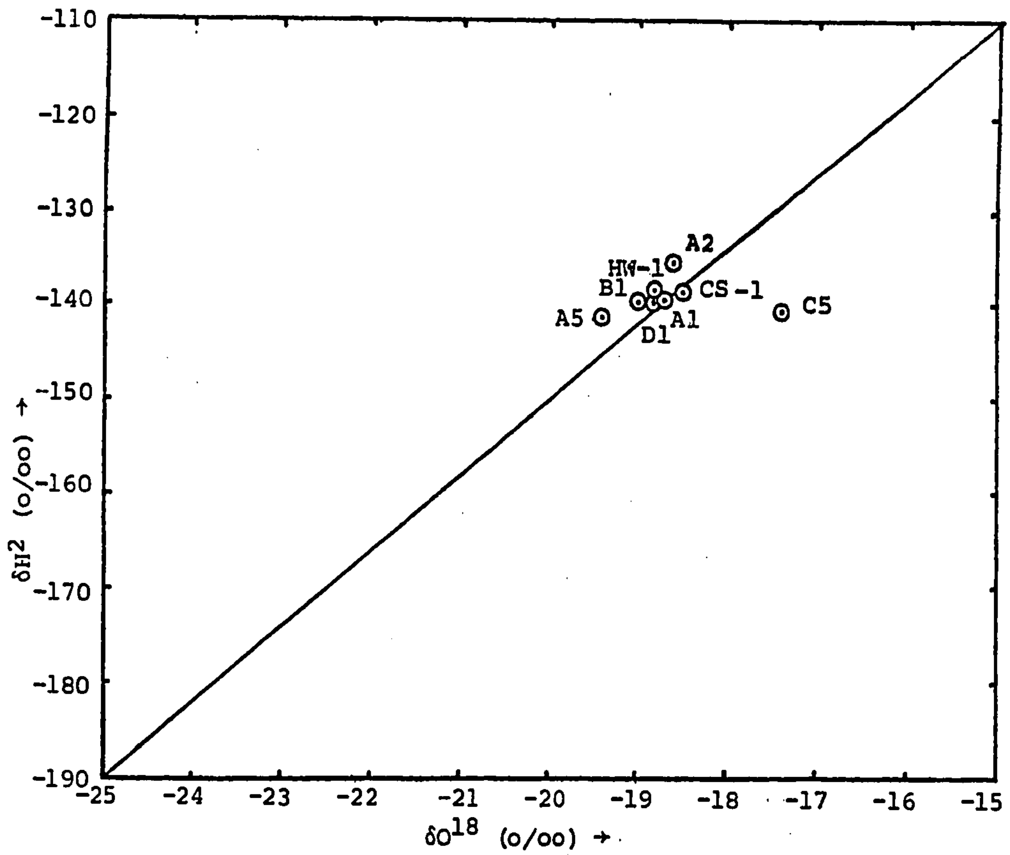


Figure 13: Plot of δO^{18} vs. δH^{2} compositions of thermal springs, Karshner Creek and a warm well in the Manley Hot Springs area. The line represents the meteoric water line.

C,5 does show a higher O^{18} value than other samples it is not believed to be the product of more extensive isotopic exchange within the reservoir. From field relations and shallow ground temperature studies which will be discussed in later sections, seeps of Site C appear to be the result of subsurface gravitational flow of thermal water from upper spring sites. As such, the isotopic compositions of Site C water should be quite similar to those of Sites A, B and D. Differences may be due to sampling, and/or analytical error. In general however, O^{18} and H^2 content of thermal waters at Manley Hot Springs are quite similar to those of local groundwater, suggesting they are the results of deep circulating meteoric water which has not undergone oxygen isotopic exchange with the rocks.

ENERGY STUDIES

Heat Discharge

The mean temperature for springs A,1-8 at Manley Hot Springs is 50°C (seep A,8 contributes a very minor portion of the total effluent and therefore it's temperature is disregarded). With an average cold water temperature of 15°C, this would give a temperature differential of the main spring system of 35°C. The heat discharge is the product of the temperature differential and the flow rate (1,418 l/min), converted to calories/second, giving a total heat discharge of the main springs of 8.27 x 10^5 cal/sec or 3.5 megawatts. It should be kept in mind that the heat discharge value of the surface system is not the same as the amount of directly useable energy.

Rankin Cycle Generator

In the summer of 1981, John Aspnes and John Zarling with the School of Engineering, University of Alaska installed an Ormat organic rankine cycle turbine generator at the hot springs. This was the second phase of a two-phase research project conducted by the State of Alaska, Division of Energy and Power Development. The project's purpose was to determine the feasibility of utilizing low-grade geothermal and waste heat by means of the Israel-built binary system generator. The Ormat rankine cycle generator has a 3 kw capacity. Cold (3.8°C) water from Karshner Creek was fed into the condenser side of the heat exchanger, while hot (49°C) water from the main springs was fed into the boiler/evaporator heat exchanger. The generator provided slightly over 1000 watts of power at 2.3% efficiency for a period of about 15 hours. However, several problems were encountered. The inverter which converted electricity from DC to AC was malfunctioning and required repair, as did the loadswitching circuit and vapor valve actuator on the Ormat unit. In addition, the inlet filter on the hot and cold water supply required constant cleaning, also the Ormat unit and intake and outlet pipes would have to be insulated in order to operate under winter conditions. The expense entailed in fixing these problems was not economically justifiable at the time.

GROUND TEMPERATURE SURVEYS

Two ground temperature surveys were conducted at Manley Hot Springs (Figures 14 and 15). An earlier temperature survey was done over the established grid system and concentrated on thermal anomalies around Site A and to a lesser extent Sites B and C (Fig. 14). Since the area of thermally disturbed ground extends beyond the grid, a later temperature survey was conducted which covered a larger area including Site D and established "background" of non-thermally disturbed ground (Fig. 15). The temperature surveys were shallow, utilizing a probe which measured the ground temperature at a depth of 0.50 meters below the surface. As shown in Figs. 14 and 15, it appears that shallow-level geothermal activity can be adequately delineated at this measurement depth.

The temperature probe was designed by Tom Osterkamp of the Geophysical Institute, University of Alaska, Fairbanks, and constructed at the Institute's machine shop. Several modifications were later made to the original probe by Cy Hetherington and Joe Redington, Jr. of Manley Hot Springs. The probe consists of a hollow length of steel which is pounded into the ground. A thermistor is lowered down inside the probe and the probe is then filled with water to allow for better heat transfer between the probe and the thermistor. It takes 2 to 3 minutes for the temperature to stabilize. The temperature reading is taken from the thermistor meter which can be read to an accuracy of ± 0.1° C. To ascertain if shallow ground temperatures are affected by solar

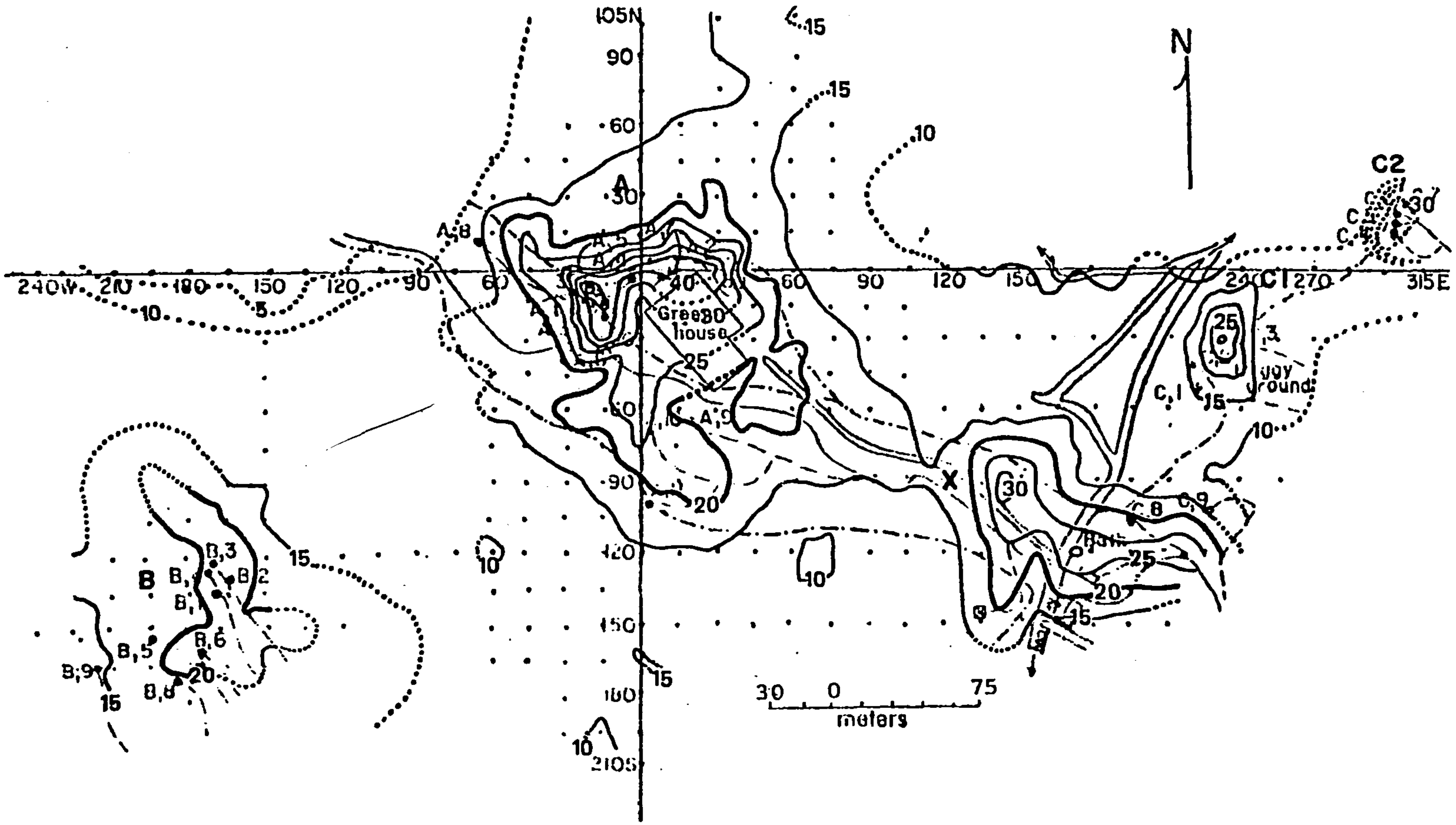


Figure 14: Shallow (0.5 meter) temperature isotherm of grid. Temperature values in degrees Centigrade, lines dotted where approximate.

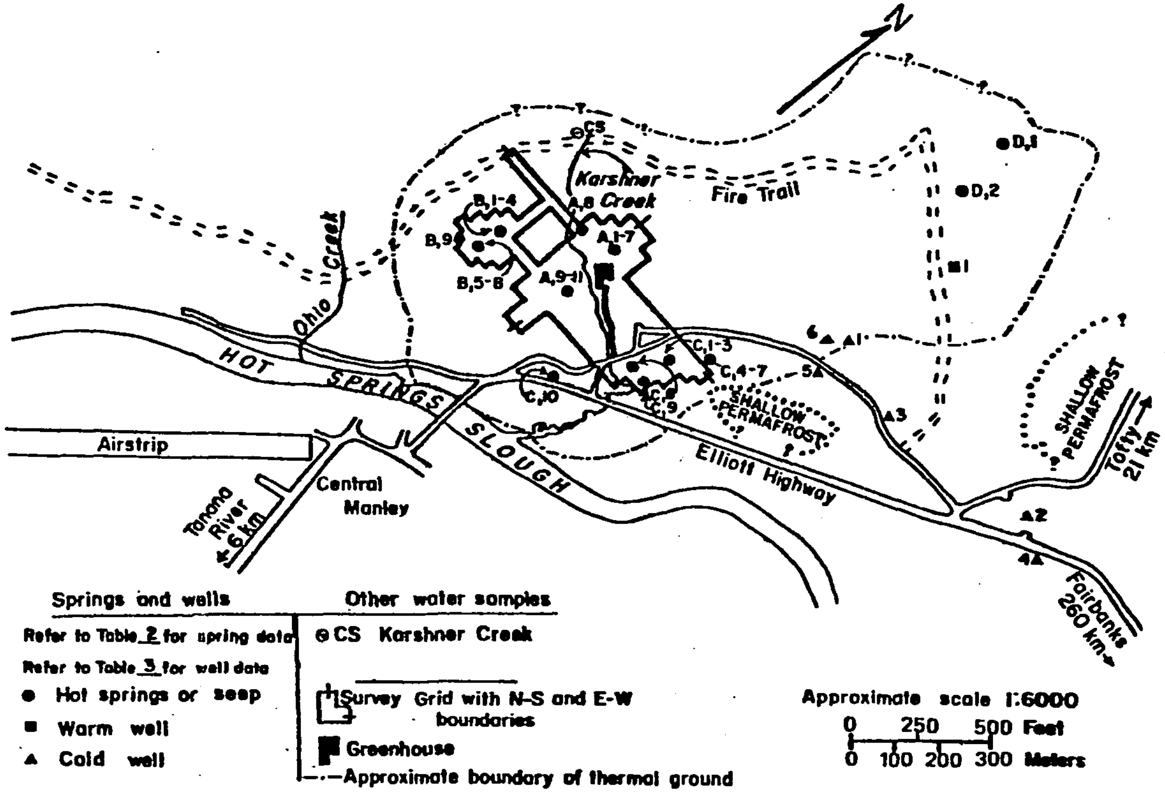


Figure 15: Extent of regional thermal anomaly at Manley Hot Springs.

heating on an hourly basis, the temperature of a control point was measured several times though the period of one day. It was concluded that the ground temperature at a level of 0.5 m was not significantly affected by the time of day at which the temperature was taken. It was noted however that as the summer progressed, the ground at a depth of 0.5 m gradually warmed due to the accumulation and storage of solar heat. Two control points measured at the end of 12 days showed an average increase in temperature of approximately 8.0%. Another point measured after 38 days showed an increase in temperature of 17.0%. To minimize the effects of long-term solar accumulation, each temperature survey was carried out over the shortest possible timespan. The grid survey was carried out in 6 days, while the reconnaissance survey was carried out in 8 days.

Grid Temperature Survey

Temperature measurements over the grid area were taken at regularly spaced intervals of 15 m. The temperatures were then plotted and hand contoured, using a contour interval of 5.0° C (Figure 14). Areas of the grid which have a sampling interval much greater than 15.0 m may have dashed isotherms to indicate that the location is approximate.

Several thermal anomalies were noted, and are defined as areas enclosed by the 20°C isotherm, shown as a heavy line on Figure 14. The largest and hottest anomaly, referred to as Anomaly A, encloses the main springs and the area of spring Site A. Temperature Anomaly A derives its name from the spring site which it partially encloses.

Anomaly A contains two small lobes with temperatures in excess of 30°C, both located northwest of the greenhouse. The hottest recorded ground temperature is 52.5°C, located just north and west of springs A,1 and A,3-5. The hot spot is near the base of the knoll, on slightly sloping, rocky and sandy ground which has a dry, baked appearance and supports little vegetation. The "baked zone" is about 4 m^2 in area. Another hot area within Anomaly A is located upslope on the top of the knoll, and is centered near spring A,2. Though irregular in shape, Anomaly A has a 120 m long major axis which trends N40E.

Another anomaly defined by the 20°C isotherm is present near spring site B and is referred to as Anomaly B. The anomaly is centered around several of the seeps. Anomaly B has a maximum ground temperature of 26.5°C located east of seep B,1. The anomaly is elongate, about 106 m long, and is oriented parallel to the spring drainages and slope direction of the hill.

Three anomalies exist on the eastern side of the grid at lower elevations in the general area of spring site C. The two northern-most anomalies referred to as anomalies C1 and C2, are each less than 25 m^2 in area. They are centered on seeps which occur along the base of steep slopes along the margin of the main valley. A third anomaly, extends along the north side of Karshner valley southeast into the main valley. The anomaly is approximately 105 m long and contains 3 areas where the temperature is in excess of 30°C. Anomaly X differs from the other shallow temperature anomalies within the grid in that it is not closely associated with surface thermal water. After a snowfall, the section of road which intersects Anomaly X is the first part of the road to melt (Charles Dart, pers. comm., 1981).

In general, 5 shallow temperature anomalies are present within the grid and are defined as areas enclosed by the 20°C isotherm. These anomalies are referred to as anomalies A, B, C1, C2 and X. The hottest and largest of these anomalies, Anomaly A, is centered around the main springs of Manley Hot Springs. All of the anomalies except Anomaly X are associated with the thermal waters of spring sites A, B and C. Anomaly X lies along and runs parallel to Karshner Creek valley. The anomaly is probably associated with very shallow level hydrothermal activity.

Reconnaissance Ground Temperature Survey

The ground temperature survey done on the grid system made it possible to delineate accurately local, higher-temperature anomalies. However, the grid did not extend into what was considered to be true "background" temperature (thermally undisturbed ground) for the Manley Hot Springs area. Anomalies A, B, C1, C2 and X appear to be superimposed on a low-level thermal anomaly which covers a major portion of the grid and extends well beyond its boundaries. Areas outside of the grid such as warm seeps of site D and the warm well HW-1 should be considered as part of the geothermal system present at Manley Hot Springs. In order to determine the actual boundaries of the low-level thermal anomaly and to tie in geothermal areas outside of the grid, a reconnaissance temperature survey was conducted. The locations of temperature measurements were plotted on BLM 1:6,000 aerial photos.

It was concluded from the reconnaissance temperature survey that the temperature for local "background" at a depth of 0.50 m is generally less than 10.0°C. Areas mapped as thermally disturbed ground met the criteria of shallow-level temperatures greater than 10.0°C. Areas of shallow permafrost were mapped where temperatures of 2.0°C or less were measured. Based on the reconnaissance temperature survey, a local thermal-anomaly map was constructed on a 1:6,000 aerial photo base (Figure 15). In general, the > 10°C anomaly is about 1.2 km long by 0.6 km wide and trends northeast near the base of south-facing slopes of Bean Ridge. South of the anomaly temperatures drop off quickly to the Hot Springs Slough. The ground is poorly drained in places with scattered shallow permafrost. There are also several cold wells present in this area. East of the anomaly is a wide valley where temperatures drop off gradually and vegetation changes to black spruce and other cool soil plants. In this area there is also scattered permafrost just west of the Tofty Road. West of the regional temperature anomaly, along the base of the slopes of Bean Ridge, temperatures drop off gradually. In a westerly direction temperatures are consistently less than or equal to about 10.0°C for 0.7 km. The extent of the northern boundary is not well defined, and is shown as a questioned line in places in Figure 15. The northern boundary is shown as upslope of an old fire break and is located within dense forest. Accurate mapping on aerial photos was difficult, and the northern boundary may be mislocated by as much as 10-15 m.

The temperature anomaly shown in Figure 15 may be helpful in indicating areas with a higher probability of geothermal potential. This map is only based on shallow temperature measurements however, and should not be construed as definitively indicative of areas which do or do not have geothermal potential.

MERCURY SOIL SURVEY

Mercury deposits are often associated with areas of geothermal activity. The high vapor pressure of mercury when combined with elevated temperatures near geothermal reservoirs allows the mercury to become highly mobile (Matlick and Buseck, 1975). It may then migrate upward and away from the reservoir, concentrating in soils overlying and adjacent to geothermal areas. The high mobility of mercury can thus make it a useful tool for geothermal exploration.

At Manley Hot Springs, a mercury-soil sample was collected at each of the grid points - a total of 287 samples (Figure 16). Each of the samples was collected below the organic horizon at a standard depth of 10 to 15 cm. Samples were dried in the shade, sifted through an 80 mesh screen, and then stored in glass vials. Analysis was done from October to December, 1981 on a Jerome Instruments Model 301 gold film mercury detector, with a detection level of about 1 part per billion (ppb). A low-temperature method of analysis was done on the Model 301 mercury detector, in which samples were heated to temperatures of 290°C rather than the high-temperature analysis involving heating to 800°C. The low temperature analysis drives off less mercury so that mercury values are about 40-60% lower than those using the higher temperature analysis. This method of reduced soil heating gives relative, not absolute values for mercury and is often perferred because of improved reproducibility and ease of analysis. Samples of 0.25 g were run in duplicate in order to insure reproducibility of results. Values for duplicate

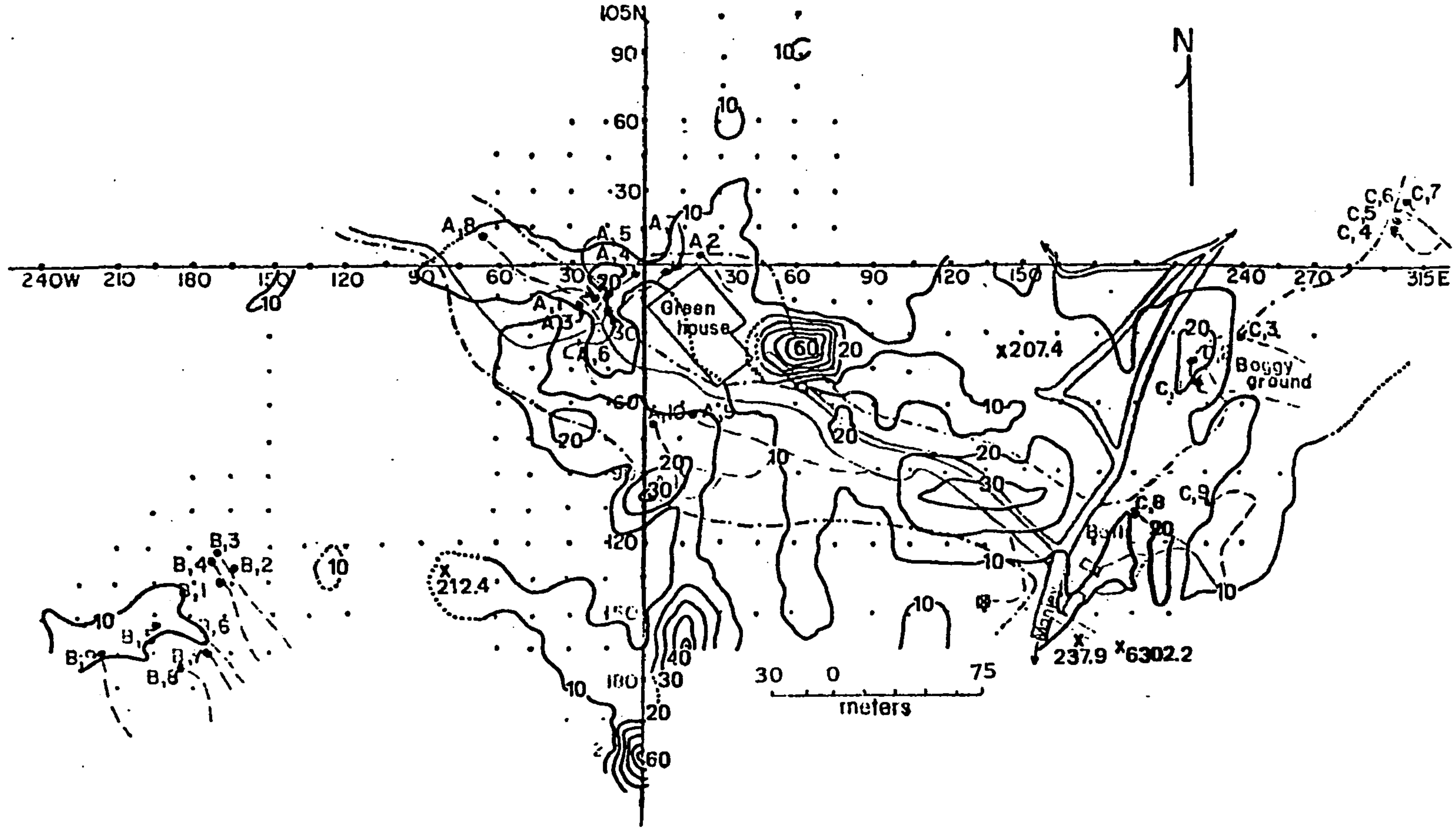


Figure 16: Mercury soil map. Values are in parts per billion (ppb), and lines are dotted where approximate. Plots with X's and a value (ie: X 237.9) are considered anomalous.

samples were generally within ± 0-18% of each other. Results of the mercury analysis were plotted and hand-contoured, using a contour interval of 10 ppb mercury (Figure 16).

The majority of samples had values of about 5 to 15 ppb. Background mercury values for the grid are about 4 to 9 ppb. However, it should be kept in mind that the numbers are relative and not absolute values. A few soil samples had very high mercury contents, ranging from 107 to 6,300 ppb. Based on their site of collection, it is believed that these are not the result of geothermal activity but are the product of soil contamination. The 6,300 ppb value was collected by Karshner Creek near an area used by a gold miner for panning and amalgamation. Other areas of extremely high mercury values are characterized by unnatural soil disturbance and/or abandoned machinery close to the sample station.

There are two large areas enclosed by the 10 ppb contour. One of the areas is along the northern side of Karshner valley and on part of the hill north of the valley. The other anomaly is U-shaped and covers part of the southern side of Karshner valley and a portion of the hillside south of the valley.

Values on the order of 20-60 ppb are probably associated with geothermal activity. The exception to this might be the two anomalous areas on the south-central edge of the grid. They show values of 52 and 72 ppb and are located on a wooded hillside which is not close to any hydrothermal area. The other 20-60 ppb anomalies are near or within hot spring sites. Several of the apparently geothermal-related mercury anomalies are 1-5 m upslope of spring or seep sites. A 14 ppb anomaly is located just upslope and west of springs of site B. A 32 ppb anomaly is upslope of springs A,10-11. A 24 ppb mercury value is upslope of springs A,1 and A,3-4, and a 27 ppb value is above springs C,1-3. This may be due to higher temperatures allowing mercury to be driven off. There are no large mercury anomalies in soil associated with the main hot springs. There is a 77 ppb anomaly just east of the greenhouse on the north wall of Karshner Creek valley. There is also a linear, east-west trending anomaly of greater than 30 ppb which is in the lower part of Karshner valley and upslope of temperature Anomaly X.

In summary, there appears to be a correlation between most higher mercury values and proximity to the hot springs. Several of the mercury anomalies occur 1-5 meters upslope of hot springs and seeps, as well as a mercury anomaly upslope of temperature anomaly X. Wescott (1981) found a good correlation between ground temperature and Hg values at Chena Hot Spring, however at Manley Hot Springs this does not seem to be the case. Mercury values over higher temperature ground, such as the "baked zone" are not appreciably lower or higher than average.

EM31 SHALLOW-LEVEL RESISTIVITY SURVEY

A shallow resistivity survey was run over the grid system to determine lateral and vertical variations of ground resistivity at Manley Hot Springs. The Geonics EM31 instrument consists of coplanar transmitter and receiver coils located at opposite ends of a 3 meter boom. The transmitter coil induces circular eddy current loops in the earth, such that the magnitude of any one of the current loops is directly proportional to the terrain conductivity in the vicinity of that loop. A magnetic field is generated by each of the current loops which is proportional to the value of the current flowing within that loop. The receiver coil intercepts a part of that magnetic field and results in an output voltage which is also linearly related to the terrain conductivity. Assuming the earth is uniform, the instrument reads the actual terrain conductivity. However, if the earth is layered with layers of different conductivity values, the instrument reads an intermediate value. The EM31 has a recorded accuracy of ± 5% at 20 millimhos per meter. In general, the EM31 acquires most of its conductivity response from shallow ground levels with lesser response from deeper levels. For example, the ground below 6 meters contributes about 28% of the total conductivity response, while the ground below 9 meters yields about 20%.

The instrument does not require electrical contact with the ground so that measurements can be taken relatively quickly. During the survey the instrument was read at a height of about 1 meter from the surface. Readings were taken in conductivity units of millimhos per meter which were later converted to resistivity units of ohm-meters. The transmitter was kept oriented towards the east. It was unnecessary to apply drift corrections to the data, as base station readings throughout the period of the survey showed relatively little change. Meter readings tended to fluctuate wildly where stations were located next to metallic pipes. At these locations the data were either disregarded or the instrument was moved far enough so that readings were not affected.

The results of the EM31 survey are shown in Figure 17. The data are given in units of ohm-meters and are hand-contoured using a contour interval of 20 ohm-meters. Values range from a high of 500 ohm-meters to a low of 14 ohm-meters. In general, background is considered to be greater than 80-100 ohm-meters, while anomalous values have been designated as about 60 ohmmeters or less. The 60 ohm-meter contour encloses two large areas. One area is centered over the knoll, including the greenhouse and some of the main springs. This anomaly corresponds quite closely with the floor of Karshner valley from 20 meters northwest of the greenhouse to about 25 meters southeast of the greenhouse. Another anomalous area enclosed partially by the 60 ohm-meter contour is located on the north edge of the main valley with a small arm extending up into Karshner valley. There is also a small, anomalous area near the springs of site B.

The resistivity lows appear to correspond closely with surface or nearsurface expressions of thermal water. As shown in Figure 17,

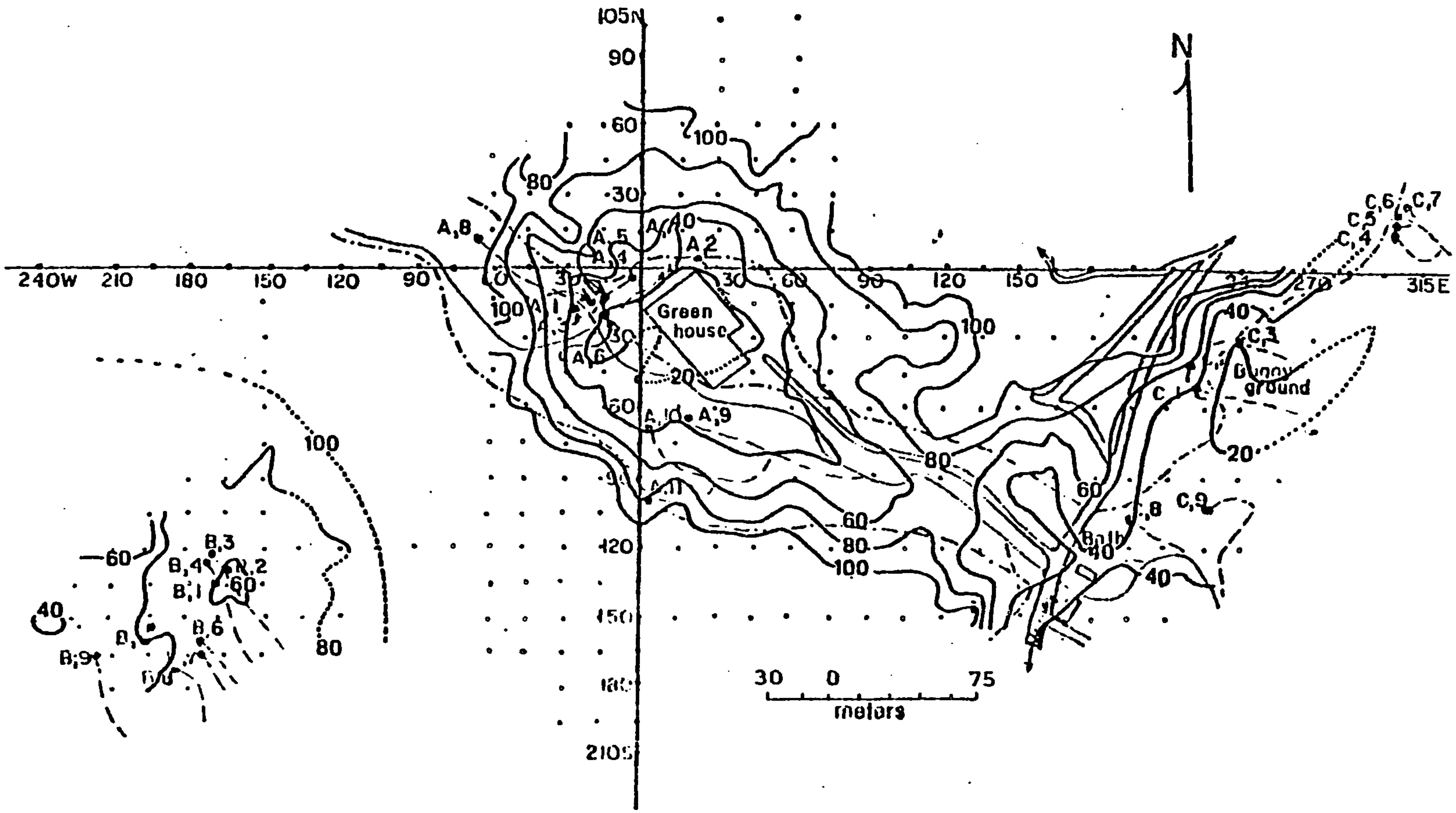


Figure 17: EM31 shallow-level resistivity. Values are in ohm-meters, and contours are dotted where approximate.

resistivity lows are usually proximal to warm springs and seeps. The high temperature, and partially saline nature of the hot spring waters accounts for the low resistivity values. Hot Springs Slough, which is slow-moving, murky water, and is probably high in suspended particles and dissolved constituents, also shows low resistivity values. The resistivity near or over water of Karshner Creek before thermal mixing has taken place is not anomalously low.

Based on exposures along the walls of Karshner valley and steep slopes bordering the main valley, it is believed that the loess forms continuous deposits at least 10-12 meters thick on the hillsides surrounding the hot springs. Therefore, on the hillsides the depth to bedrock is at a minimum of 10-12 meters. Assuming the EM31 is seeing a homogeneous earth on the hillsides, the resistivity of the loess is believed to be about 200 ohm-meters. Upstream from the hot spring area, where readings are not strongly affected by thermal water, the resistivity is similar to that of the loess-covered hills. This indicates that loess may underlie alluvium of Karshner Creek valley. Assuming the alluvium layer is thin enough so that the EM31 is seeing relatively homogeneous earth near the upper part of Karshner Creek, the depth to bedrock in the creek may be 5-6 meters or more.

EM16R (RADIOHM) RESISTIVITY SURVEY

An attempt was made to measure variations in resistivity at deeper levels than those obtained by the EM31 survey. The Geonics EM16R was the instrument used for this purpose. To determine the electrical resistivity of the ground, the EM16R measures the ratio and the phase angle between the horizontal electric and magnetic fields of the wave propagated by distant VLF (very low frequency) transmitters. If the earth is of uniform resistivity there is a phase angle of 45° between the electric and magnetic field components, and the EM16R reads the true terrain resistivity. The effective depth of penetration depends on the electrical resistivity itself and to a minor extent, on the frequency of the transmitting station. The higher the terrain resistivity, the deeper the depth of penetration. If the resistivity is 200 ohm-meters the penetration depth at a frequency of 20 kHz is 50 meters. However, if several layers of different resistivities are present and the depth of penetration of the EM16R is deeper than the upper layer, then the instrument will read an intermediate resistivity value and the phase angle will no longer be 45°. In a two-layer case, if the resistivity of either layer or the thickness of the upper layer is known, then from the apparent resistivity and the phase angle the other two parameters, e.g. the thickness of layer 1 and the resistivity values of the other layers can be found by comparison with a series of two-layer model curves or by calculations. Calculations for three or more layers are quite complex.

The EM16R makes electrical contact with the ground by means of 2 probes spaced 10 meters apart. The probes are aligned with the direction of the VLF transmitter. The transmitter used for this study is based in Seattle, with a transmitted frequency of 18.6 kHz. Phase angle and resistivity readings were obtained by locating an audio nullpoint. Stations which were covered by the EM16R survey are shown in Figure 18. A total of 61 stations were measured covering segments of 5 east-west grid lines. Profiles for these lines are shown in Figure 19A-F. Each profile gives the grid line, the station locations and the variations in phase angle and resistivity. Phase angle is read from the right side of the graph, and resistivity values from the left. The phase angle readings are indicated by a dashed line. The horizontal dotted line indicates the 45° phase angle of the homogeneous, one-layered case.

From the profiles, the apparent resistivity values are on the average very low, usually less than 50 ohm-meters. The phase angle is usually equal to or greater than 45°. At some stations phase angles approach the 45° line, which is indicative of homogeneous ground. Stations 70W to 45E along line 00N are all quite close to a 45° phase angle, with resistivities of 30-50 Ω-m which indicates homogeneous resistivity to a depth of 20-25 m. This part of the line is located on loess slopes of the north wall of Karshner Creek and on the knoll, which consists of silty and gravelly sand. It is also in an area of high thermal disturbance associated with high temperatures and flow activity of the main springs, indicating that hot water fills the loess and aluvium to 20-25 m depth.

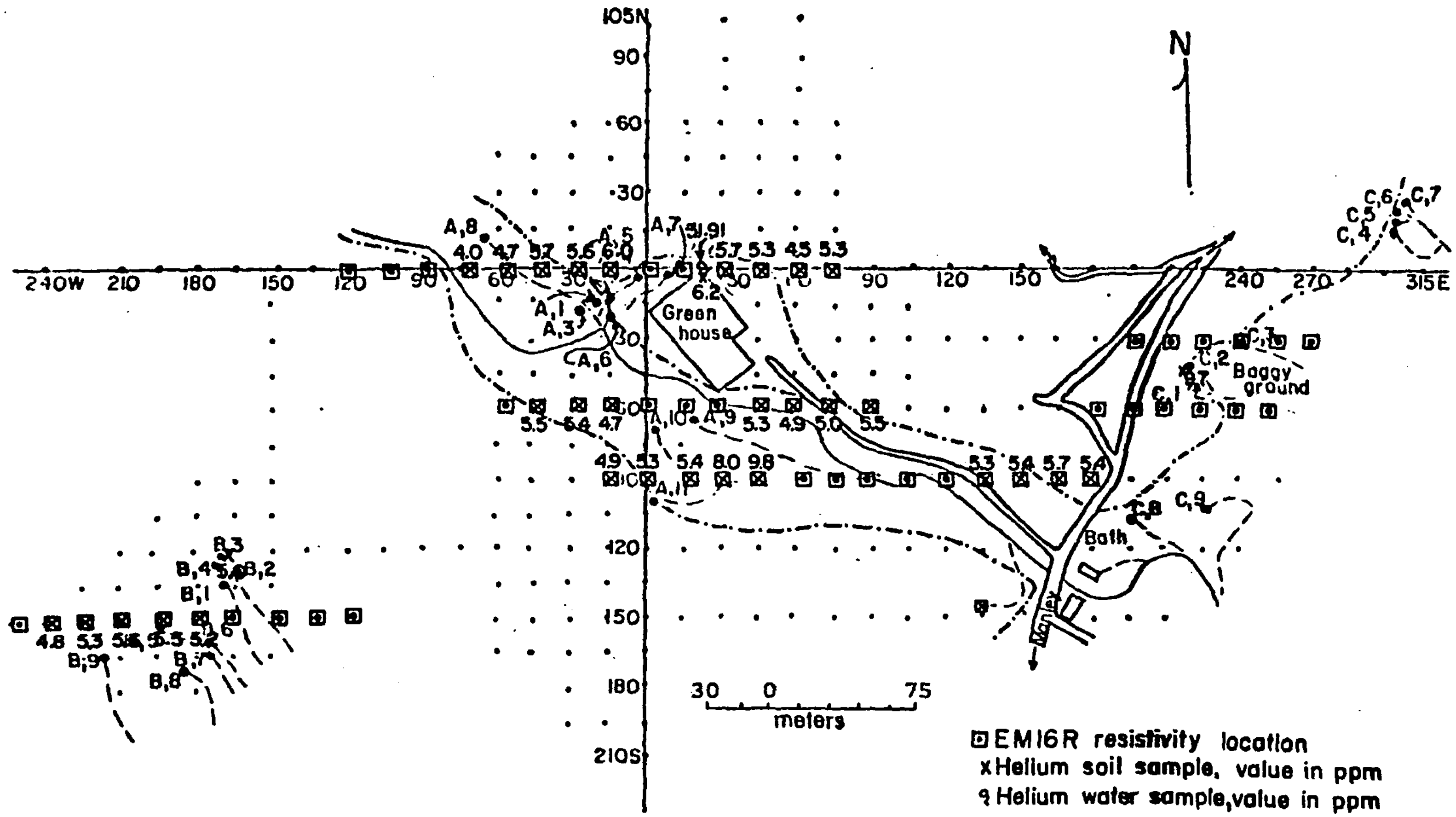


Figure 18: Location of EM16R survey lines and helium values.

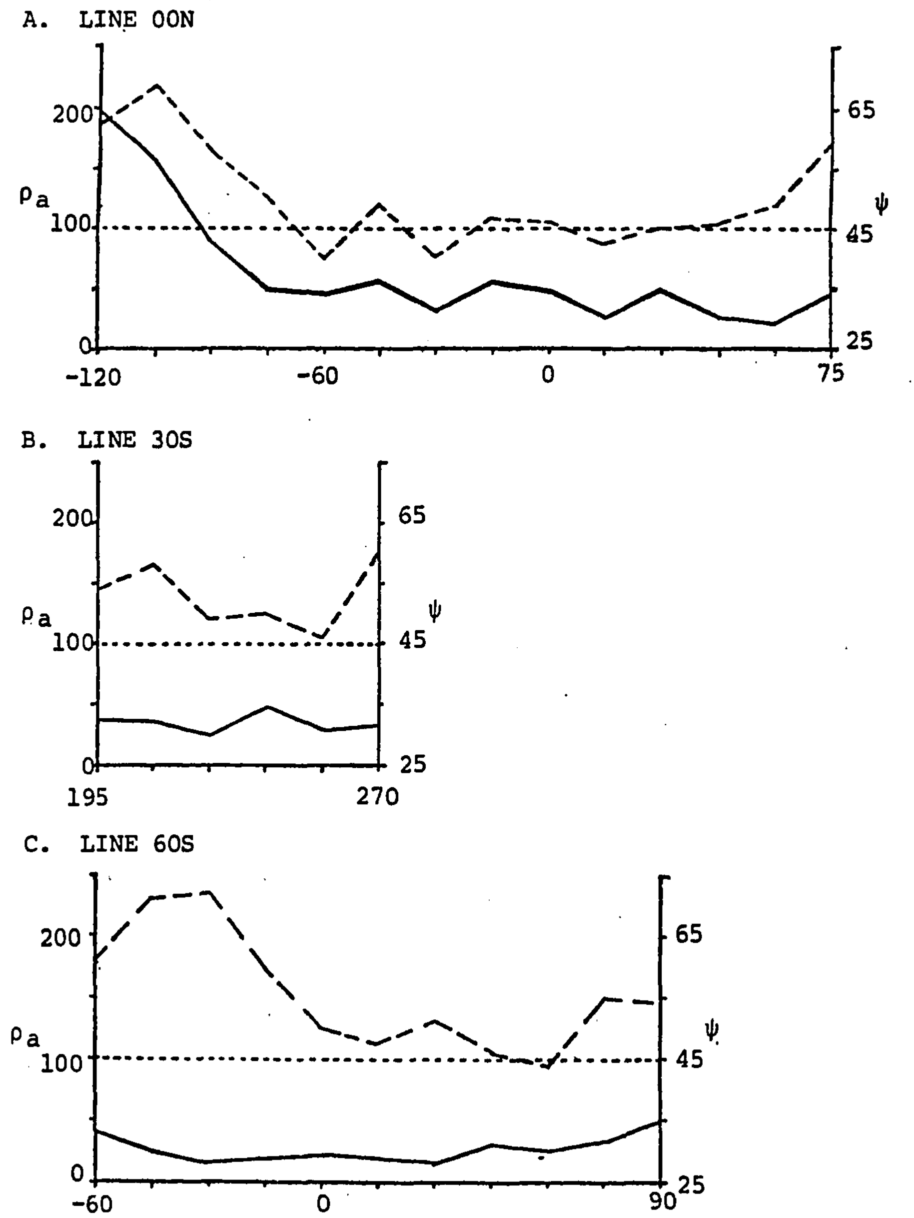


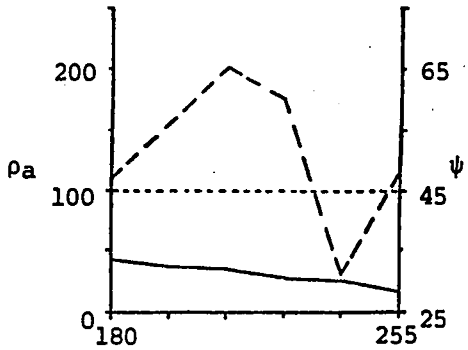
Figure 19A-F: EM16R resistivity profiles along segments of east-west lines. Apparent resistivity (ρ_a) values are read from the left of graph, phase angle (ψ) values are read from the right.

——— = ρ_a

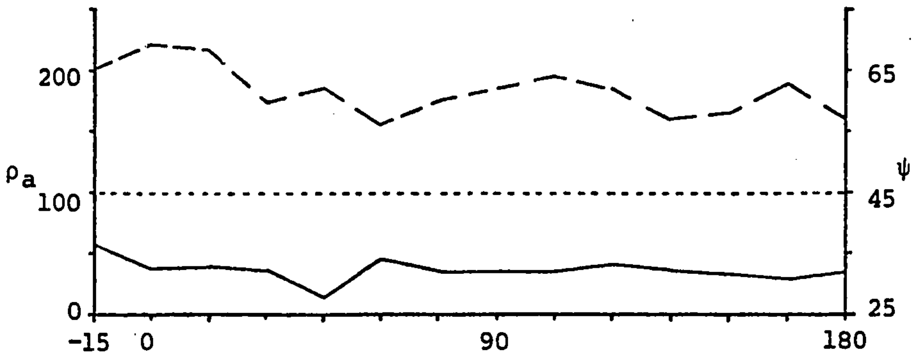
— — = ψ

- - - - = 45° phase angle for homogeneous ground

D. LINE 60S



E. LINE 90S



F. LINE 150S

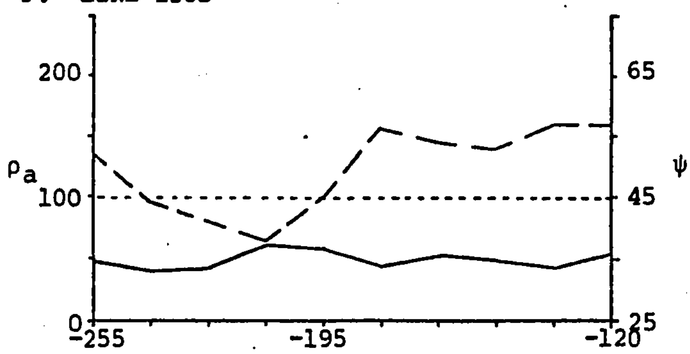


Figure 19A-F, continued.

Most of the stations show phase angles greater than 45° and low apparent resistivities. To obtain a solution using a two-layer case, it must be assumed that the resistivity of layer 2 (ρ^2) is less than the resistivity of layer 1 (ρ_1). The layer 1 resistivity was calculated to be greater than or equal to about 100 ohm-meters. Using this value, the resistivity of layer 2 is small, averaging about 10-40 ohmmeters, and the thickness of layer 1 ranges from 1-10 meters. For several other stations a solution was obtained by assuming a ρ_1 of 10-30 ohm-meters. Corresponding ρ_2 values ranged from 25-90 ohm-meters at depths of 0.5-15 meters These values may not agree with projections of near surface geology.

It appears therefore that the EM16R resistivity values are greatly affected by thermal disturbance in the area, as shown by the overall anomalously low resistivities for both layers 1 and 2. This is substantiated by the EM31 results which also yield low resistivity values over thermal ground. With it's greater depth of penetration, the EM16R results may indicate the presence of probable hot water aquifers of 20 or more meters in depth which would be located beneath the eastern segment of Line 00N and over most of the lengths of the other five lines. This suggests that much of Karshner Creek valley and portions of the adjacent hillsides may be underlain by thermal water and that the lines were not extended far enough to reach background conditions. Due to thermal disturbances, the EM16R data are insufficient to determine completely the depth of alluvium, the depth to bedrock in Karshner Valley, and the depth to bedrock on the hillsides.

HELIUM SURVEY

The helium content of soil gas is often anomalously high in areas where deep circulating water rises to the surface. Helium has been found to be a good geothermal indicator in several Alaskan areas (Wescott, 1981; Wescott and Turner, 1981; and Turner and Wescott, 1982). Helium is formed as a by-product of the radioactive decay of uranium and thorium. These elements are present in minor amounts in most rocks and can be enriched in granitic intrusive rocks. The solubility of helium in water increases with temperatures above 30°C, so that thermal water coming from depth may act as an efficient helium scavenger (Mazor, 1972). As the water reaches a near-surface reservoir, it undergoes cooling and a drop in pressure. Both of these conditions effectively release the helium which may then rise towards the surface.

There are several different methods for helium sampling. Samples of gas can either be extracted from the soil by a driven tube, or samples of soil can be canned, and the gas within the soil later analyzed. The gas within the thermal water can also be collected and analysed for helium. At spring A,2 one helium water sample was taken. Sampling for the helium survey at Manley Hot Springs primarily consisted of canning soil samples. The soil was collected from a 0.6 m depth with a soil auger and then canned as quickly as possible to minimize the loss of helium. Cans were shipped to Western Systems, Inc. in Colorado for mass spectrometric He analysis, with results being reported in parts per million (ppm) helium with a precision of 10 parts per billion.

Figure 18 shows the grid stations where helium soil samples were collected and the corresponding values of helium in ppm. A total of 33 samples were analysed for helium, mostly taken along east-west grid lines. The sampled stations were previously known to have high temperature values and low shallow-level resistivity values. The normal air concentration of helium is 5.24 ppm. Helium levels at Manley Hot Springs range from 4.0 to 9.8 ppm, with values of approximately 6.0 ppm or greater considered anomalous. The highest value of 9.8 ppm was taken along line 90S. The station is located on the valley floor near drainages of springs A,10-11. The neighboring sample was also anomalous, with a value of 8.0 ppm. The soil was collected from gravelly and sandy alluvium of Karshner Creek. The main spring area shows maximum values of 6.0 and 6.2 ppm, and a water sample collected at spring A,2 had a value of 31.9 ppm helium. Water samples generally run higher than soil values, but 31.9 ppm is anomalously high (Turner and Wescott, 1982). The other high helium value was taken in soil near spring C,2 and contains 9.7 ppm He.

The highest soil reading of 9.8 ppm helium was taken from ground with a shallow temperature of 21.5°C, while the two high values near the main springs had ground temperatures of 30.0° and 42.5°C. Since helium is an indicator of thermal water which has ascended from depth, these localities may represent areas where fracturing or faulting has allowed the deeply circulating water to ascend to the near surface. As such, these areas might be likely targets for geothermal drilling.

CONCLUSION

Based on the above evidence, a model is proposed for the low temperature geothermal system present at Manley Hot Springs (Fig. 20A-B). Ground water along the southeast slopes of Bean Ridge enters joints and fractures in granitic rocks of the Manley Hot Springs Dome stock. The water migrates deeply enough in the granite to be heated by a normal geothermal gradient of 30-50°C/km. Given a reservoir temperature of 113 to 130°C, derived from the silica and cation geothermometers, this would imply migration to depths of about 2.3-4.3 km. As water is heated, it's lower density allows it to ascend, rising along bedding planes or fractures in hornfelsed "Boulder Ridge Formation" metasedimentary rocks. The loess, with thicknesses of up to 20-30 m, may act as a final shallow-level caprock. Loess is characteristically well-sorted and therefore should be highly permeable, however the loess adjacent to the hot springs may be clay-altered or recemented by calcite, thereby decreasing its permeability. This caprock of loess allows the hot water to migrate along the loess-metasediment interface. This is supported by EM16R findings which show areas of anomalous resistivity to depths of 20 meters or more in Karshner Creek valley. Areas of fracturing coupled with deep erosion in the loess allow for final escape of thermal water to the surface, expressed as hot springs and seeps of sites A, B and D. Another method of final escape of thermal water apparently involves subsurface migration downslope

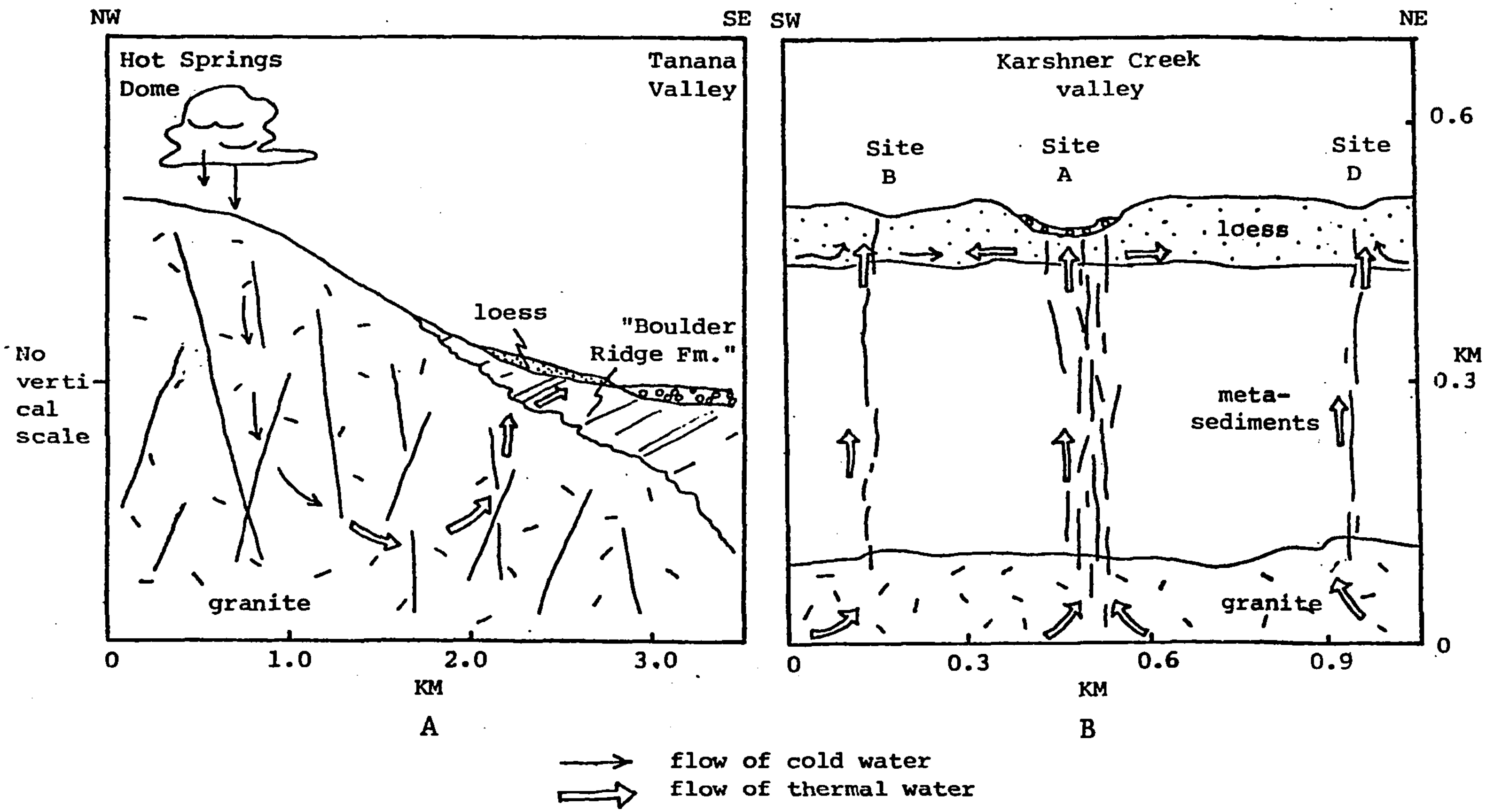


Figure 20A-B: Model for the geothermal system at Manley Hot Springs. Vertical and horizontal scales are approximate.

to the main (Tanana) valley. This may be the case for springs of site C, and temperature anomaly X.

There is a significant northeasterly trend of the regional thermal anomaly, as well as for spring sites A, B and D. The differences in elevation of the spring sites coupled with the above line of evidence, suggests structural control for the springs. Since metasediments of the "Boulder Ridge Formation" strike northeast and dip back into the Hot Springs Dome, it may be that a particular section is acting as a hot water aquifer, with thermal water migrating upward along bedding planes. A sequence of quartzites with a well-defined bedding plane cleavage would provide the necessary fracture permeability for water migration and would explain the regional northeasterly trend of the thermal anomaly and spring sites.

The migration of hot water may be further controlled by fracture or fault systems which radiate outward from the dome, with approximate northwest strikes. Karshner Creek valley may be the result of one such northwest-striking fracture zone. Where such a zone intersects the conjectured hot-water aquifer of the "Boulder Ridge Formation" a local hot-spring site may occur. Springs of site A may be the result of a well-defined northwesterly fracture system, whereas springs of sites B and D may be underlain by much smaller and less permeable fracture systems, resulting in cooler water and lower rates of flow.

No fault or fracture systems were detected; however exposures are poor so that if faulting does exist it is well-hidden. A seismic survey would aid in delineating the depth and topology of the basement in Karshner valley, as well as possible faulting. More extensive deep-level galvanic resistivity and helium surveys could be useful in defining areas of hot water source migration and detection of the fault or fracture system which may control the Manley Hot Springs geothermal area.

Based on findings from the helium, temperature, mercury, and resistivity surveys, three localities at Manley Hot Springs were chosen as likely sites for a geothermal well (Figure 21). The first and most promising site is the area just north to northwest of the greenhouse, referred to as site 1. The area is an obvious choice, since the hottest springs are located here. Helium soil gas values are anomalously high, as are shallow ground temperature, shallow and deep-level resistivity values. Site 2 is the second most likely site based on anomalous helium values. It is located on the floor of Karshner valley near the intersection of drainages of sites A,10 and A,11. Site 3, the third most likely drilling site, is located near temperature Anomaly X, just west of the main road on the north side of Karshner Creek Valley. It is characterized by anomalous temperature and resistivity values and anomalous mercury values occur several meters upslope. Helium soil gas values, however, are not anomalously high.

It should be kept in mind that surface expressions of thermal water are probably the result of displacement downslope from the heat source, along the ground water gradient. There is the possibility that a deeper-level, hot-water source may be several meters upslope of the proposed drill sites. It is initially recommended

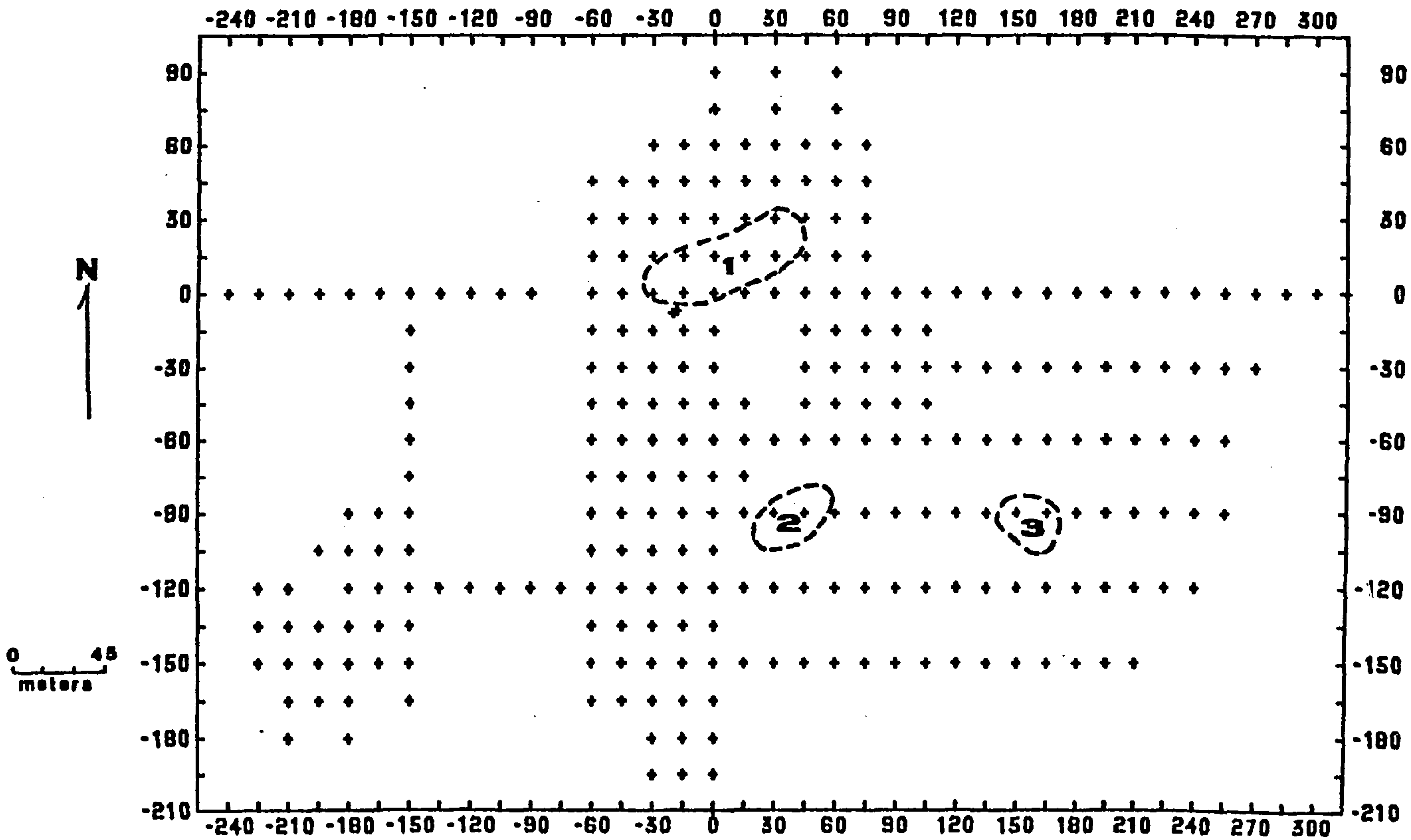


Figure 21: Proposed geothermal well sites.

that drilling be started upslope of Site 1. If hot water is not encountered by a depth of 20-30 m or so the hole can be angled to intersect the area underneath Site 1. The thermal water of Manley Hot Springs is probably mixing with cooler ground water and/or water of Karshner Creek. Drilling to an adequate depth could result in substantially hotter water, allowing for geothermal energy utilization on a much larger scale than at present.

The low-temperature geothermal resource present at Manley Hot Springs is a highly useful energy source, especially in light of its location near a small population center in the interior of Alaska. The work of Karshner and Manley in the early part of the century attests to the fact that Manley Hot Springs, as well as other hot springs of the Interior, can be utilized on a much larger scale than they are presently. Agricultural production, spaceheating and even the generation of small amounts of electricity by geothermal means could be highly beneficial to surrounding communities.

BIBLIOGRAPHY

Beikman, H. M. and E. H. Lathram, 1976, Geologic map of northern Alaska: U.S. Geol. Survey Misc. Field Studies Map MF 789, scale 1:1,000,000.

Chapman, R. M., F. R. Weber, and B. Taber, 1971, Preliminary geologic map of the Livengood quadrangle, Alaska: U.S. Geol. Survey open-file report 71-66, scale 1:250,000.

Chapman, R. M., W. E. Yeend, W. P. Brosgé, and H. N. Reiser, 1975, Preliminary geologic map of the Tanana and northeastern part of the Kantishna River quadrangles, Alaska: U.S. Geol. Survey open-file report 75-337, scale 1:250,000.

Chapman, R. M., F. R. Weber, M. Churkin, Jr., and C. Carter, 1979, The Livengood Dome Chert, A new Ordovician formation in central Alaska, and its relevance to displacement on the Tintina Fault: U.S. Geol. Survey Prof. Paper 1126-F, p. 1-13.

East, J. S., 1982, Preliminary geothermal investigations at Manley Hot Springs, Alaska: Geophysical Institute, Univ. of Alaska, Report UAG R-290.

Foster, H. L., F. R. Weber, R. B. Forbes, and E. E. Brabb, 1973, Regional geology of Yukon-Tanana Upland, Alaska: in Arctic Geology, Am. Assoc. Pet. Geol., Mem., no. 19, p. 388-395.

Fournier, R. L. and A. H. Truesdell, 1973, An empirical Na-K-Ca geothermometer for natural water: Geochim. et Cosmochim, vol. 37, p. 1255-1275.

Fournier, R. O., D. E. White and A. H. Truesdell, 1974, Geochemical indicators of sub-surface temperature - part 1, basic assumptions: U.S. Geol. Survey Jour. Research, vol. 2, no. 2, p. 259-262.

Hopkins, D. M. and B. Taber, 1962, Stratigraphy of the pre-Quaternary bedded rocks of the Manley Hot Springs area, Alaska: (prelim. and unpub.) U.S. Geol. Survey Bull., 131 p.

Leonard, Lee, 1974, What's old in geothermal energy?: Northern Engineer, vol. 6, no. 4, p. 37.

Maloney, R. P., 1971, Investigations of gossans of Hot Springs Dome, near Manley Hot Springs, Alaska: U.S. Bur. Mines open-file report 8-71, 28 p.

Mariner, R. H., C. A. Brook, J. R. Swanson and D. R. Mabey, 1978, Selected data for hydrothermal convection systems in the United States with estimated temperatures $\geq$ 90°C: backup data for U.S. Geological Survey Circular 790: U.S. Geol. Survey open-file report 78-858, 460 p.

Matlick, J. S. and P. R. Buseck, 1975, Exploration for geothermal areas using mercury, a new geochemical technique: in Proceedings of the 2nd U. N. Symp. on the Development and Use of Geothermal Resources, San Francisco, California, vol. 1, p. 785-792.

Mazor, E., 1972, Paleotemperatures and other hydrological parameters deduced from noble gases dissolved in ground waters, Jordan Rift Valley, Israel: Geochimica et Cosmochimica Acta, vol. 35, p. 1321-1336.

Mertie, J. B., Jr., 1932, The Yukon-Tanana region, Alaska: U.S. Geol. Survey Bull. 872, 276 p.

Mertie, J. B., Jr., 1934, Mineral deposits of the Rampart and Hot Springs districts: U.S. Geol. Survey Bull. 844-D, p. 163-246.

Miller, T. P., I. Barnes, and W. W. Patton, Jr., 1975, Geologic setting and chemical characteristics of hot springs in west-central Alaska: U.S. Geol. Survey Jour. Research, vol. 3, no. 2, p. 149-162.

Panichi, C. and R. Gonfiantini, 1978, Enviromental isotopes in geothermal studies: Geothermics, vol. 6, p. 143-161.

Templeman-Kluit, D. J., 1976, The Yukon crystalline terraine: enigma in the Canadian Cordillera: Geol. Soc. America Bull., vol. 87, p. 1343-1357.

Turner, D. L. and E. M. Wescott, 1982, Preliminary investigation of the geothermal energy resources of the lower Susitna Basin, Geophysical Institute, Univ. of Alaska, Report UAG R-287.

Waring, G. A., 1917, Mineral Springs of Alaska: U.S. Geol. Survey Water Supply Paper 418, 114 p.

Wescott, E. M., 1981, Helium and mercury surveys: in A geological and geophysical study of the Chena Hot Springs geothermal area, Alaska, Geophysical Institute, Univ. of Alaska, Report UAG R-283.

Wescott, E. M. and D. L. Turner, 1981, Geothermal reconnaissance survey of the central Seward Peninsula, Alaska: Geophysical Institute, Univ. of Alaska, Report R-284.